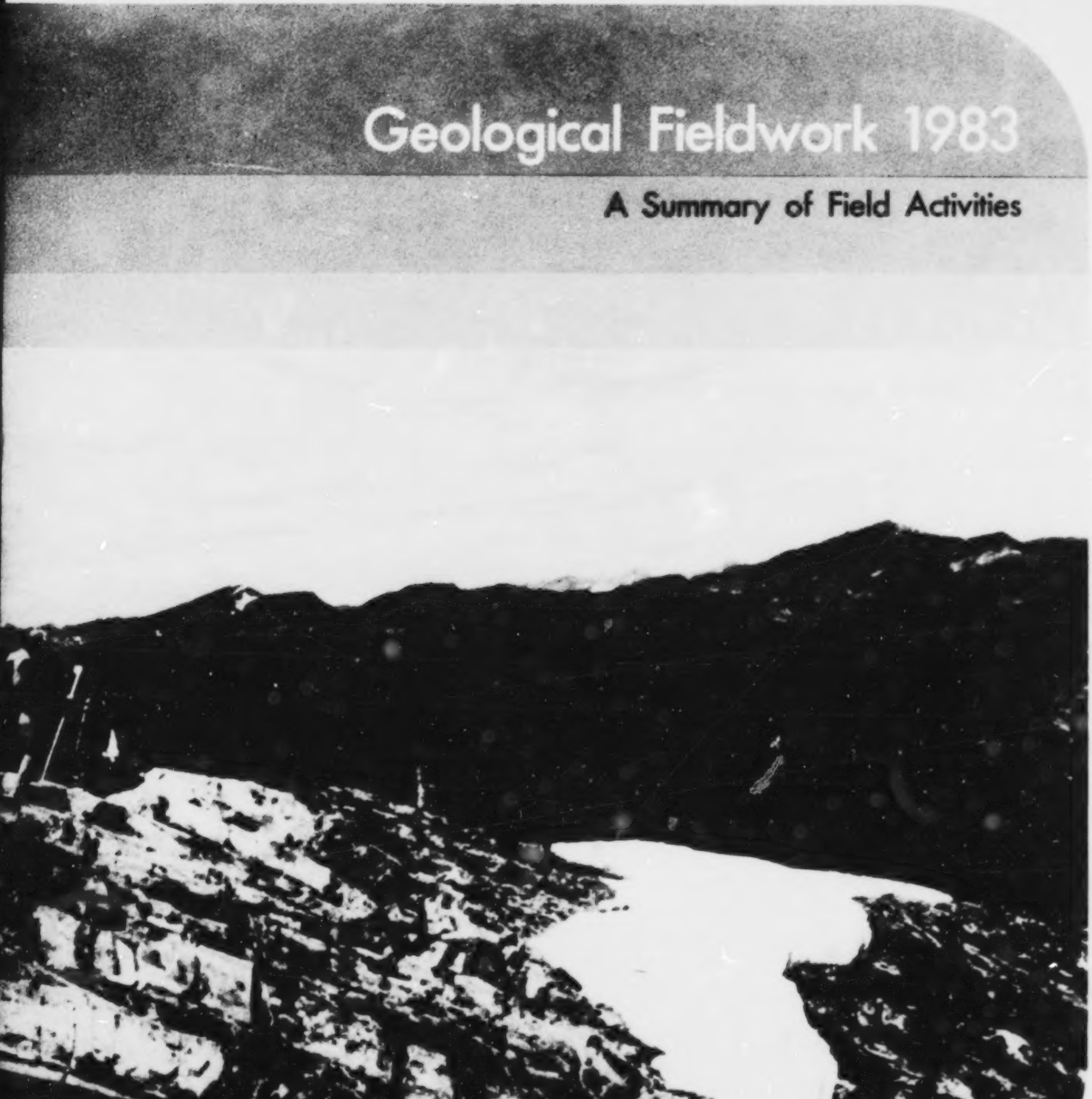
# Geological Fieldwork 1983

## A Summary of Field Activities



PAPER 1984 – 1

**Province of**
**British Columbia**

Ministry of
Energy, Mines and
Petroleum Resources

GEOLOGICAL BRANCH
MINERAL RESOURCES DIVISION

# Geological Fieldwork
# 1983

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**of the geological branch,**
**mineral resources division**
**Paper 1984 - 1**

**Province of British Columbia**
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**British Columbia Cataloguing in Publication Data**

Main entry under title:
Geological fieldwork. -- 1974-

(Paper, ISSN 0226-9430)
Annual.
Issuing body varies: 1974-1980, Geological Division; 1981- , Geological Branch.
Subseries, 1979- , of: Paper (British Columbia. Ministry of Energy, Mines and Petroleum Resources)
"A summary of field activities of the Geological Division, Mineral Resources Branch."
ISSN 0381-243X = Geological fieldwork

1. Geology - British Columbia - Periodicals. 2. Geology, Economic - British Columbia - Periodicals. 3. Mines and mineral resources - British Columbia - Periodicals. I. British Columbia. Geological Division. II. British Columbia. Geological Branch. III. British Columbia. Ministry of Energy, Mines and Petroleum Resources. IV. Series: Paper (British Columbia. Ministry of Energy, Mines and Petroleum Resources)

QE187.G46 1974 557.11'05

**Victoria**
**British Columbia**
**Canada**

**January 1984**

# FOREWORD

This is the tenth year of publication of *Geological Fieldwork*, a publication designed to acquaint the interested public with the preliminary results of fieldwork of the Geological Branch as soon as possible after the field season. The reports are written without the benefit of extensive laboratory or office studies. Figures in this year's publication were done by our draughting section.

This edition of *Geological Fieldwork* continues with the two-section format adopted in 1981 (Geological Branch Paper 1982–1). The Project and Applied Geology section includes reports of metallic and coalfield investigations by Project and District Geologists, and property examinations related to some mineral properties funded in part by Ministry programs. The Other Investigations section consists mainly of reports of work done at the University of British Columbia in cooperation with the Ministry.

The cover photograph shows a geologist measuring a section at the Sullivan horizon in Aldridge Formation rocks in the Purcell Mountains of Southeastern British Columbia.

Output of this publication was coordinated by A. Panteleyev and W. J. McMillan. Manuscript input was by J. Patenaude and layout and design were by D. Fehr of the Publication section. Draughting of the figures in the Project and Applied Geology section of the report was by R. Hoensen, P. Chicorelli, M. Taylor, and J. Armitage of the draughting office.

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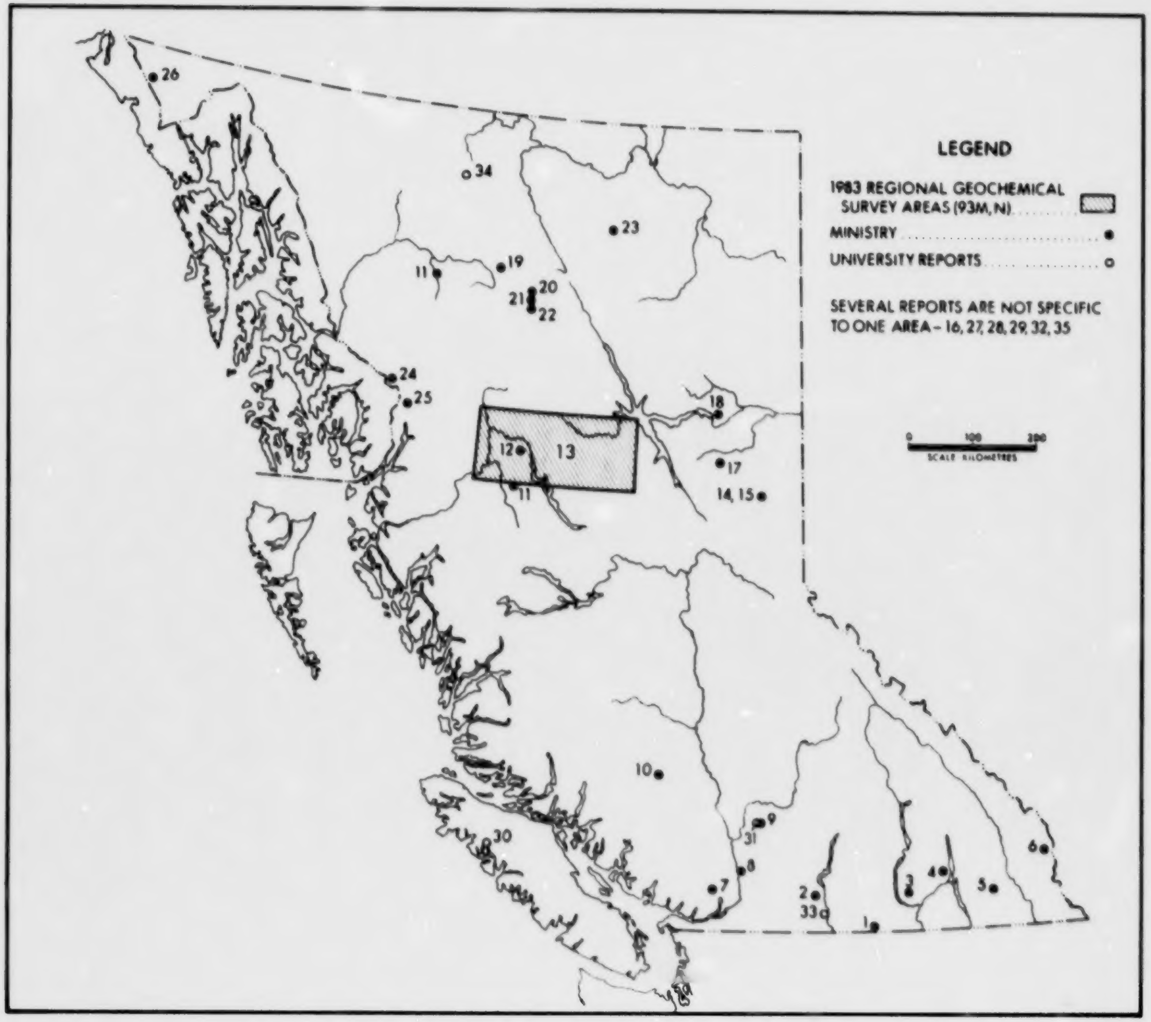
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Distribution of programs, Geological Fieldwork, 1983.

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# PROJECT AND APPLIED GEOLOGY

## GEOLOGY AND SELF–POTENTIAL SURVEY OF THE SYLVESTER K GOLD–SULPHIDE PROSPECT

## (82E/2E)

By B. N. Church

### INTRODUCTION

This report gives the results of geological and self-potential geophysical surveys completed on Sylvester K and adjacent Crown-granted claims centred 1.5 kilometres northwest of the Phoenix mine and 5 kilometres east of Greenwood. The area has experienced an accelerated program of gold exploration, initiated mainly by Kettle River Resources Ltd.

### HISTORY

The Sylvester K claim was, until recently, without much mining exploration activity since the beginning of the century when it was first staked. Several hand-dug trenches and a few shallow shafts on pyrite stringers are the only remnants from the early years of prospecting.

For many years Sylvester K was included in the extensive holdings of the Phoenix Copper Division of The Granby Mining Company Limited. In 1980 control passed to Noranda Mines, Limited and recently Kettle River Resources Ltd. acquired an option interest in the property.

The only production from the immediate area was recorded in the period 1967 to 1971. A total of 249 tonnes of ore was shipped to the Trail smelter from the Marshall Crown-granted claim, owned by San Jacinto Explorations Ltd. These deliveries yielded 11.94 kilograms of gold, 14.56 kilograms of silver, 472 kilograms of copper, 2 142 kilograms of lead, and 380 kilograms of zinc.

### GEOLOGICAL SETTING

The stratigraphic, lithologic, and structural interpretation of the area is based on numerous scattered outcrops and excavations. The main units are sedimentary rocks of the Triassic Brooklyn Formation, a microdiorite stock and associated dykes, and a number of Tertiary intrusions (Fig. 1). Steeply dipping beds, typical of the area, are the result of important folding and a complicated history of fault movement.

### BEDDED ROCKS

The Brooklyn Formation underlies most of the map-area. This is divided into two principal members comprising mainly sharpstone conglomerate at the base and a limestone sequence above. An argillaceous transition zone separates these members.

The sharpstone member consists of immature polymictic conglomerate 450 to 600 metres thick. It is characterized by an abundance of purple and grey, pebble-sized, angular chert clasts intermixed with greenstone fragments and accessory jasper, diorite, and limestone. Chemical analysis of a sample of the conglomerate from Knob Hill near the Phoenix pit (analysis No. 1, accompanying table) closely resembles the sharpstone conglomerate from Deadman Hill east of the map-area (*see* Church, 1976, analysis No. 2, accompanying table). Conglomerate beds are intercalated with green sandstone and siltstone, several limestone lenses, and discontinuous argillite layers. The 'Rawhide shale' is a local, thick shale facies developed near the base of the sharpstone member southeast of the Phoenix mine (analysis No. 2, accompanying table).

### CHEMICAL ANALYSES OF SOME TYPICAL ROCKS FROM THE SYLVESTER K AND PHOENIX AREA
### (83E/2E)

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Oxides Recalculated to 100— | | | | | | |
| $SiO_2$ | 74.81 | 68.04 | 41.05 | 54.19 | 63.12 | 60.23 |
| $TiO_2$ | 0.89 | 0.81 | 0.75 | 0.37 | 0.91 | 1.25 |
| $Al_2O_3$ | 9.55 | 13.82 | 13.08 | 15.64 | 15.43 | 18.17 |
| $Fe_2O_3$ | 0.83 | 0.43 | 6.74 | 1.12 | 2.38 | 0.56 |
| FeO | 4.91 | 6.81 | 8.59 | 6.42 | 2.73 | 4.29 |
| MnO | 0.06 | 0.06 | 0.32 | 0.13 | 0.08 | 0.09 |
| MgO | 3.69 | 4.30 | 4.49 | 8.49 | 3.30 | 1.59 |
| CaO | 2.40 | 1.07 | 24.41 | 10.39 | 4.67 | 1.95 |
| $Na_2O$ | 1.71 | 1.37 | 0.04 | 2.61 | 3.33 | 4.92 |
| $K_2O$ | 1.15 | 3.29 | 0.53 | 0.64 | 4.05 | 6.95 |
| | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| Oxides as Determined— | | | | | | |
| $H_2O+$ | 2.74 | 2.39 | 3.82 | 2.41 | 1.78 | 1.86 |
| $H_2O-$ | 0.16 | 0.20 | 0.25 | 0.11 | 0.29 | 0.54 |
| $CO_2$ | 0.89 | 1.60 | 1.21 | <0.10 | 1.80 | 0.55 |
| S | 0.07 | 0.29 | 1.59 | 0.16 | 0.01 | 0.01 |
| $P_2O_5$ | 0.25 | 0.21 | 0.20 | 0.20 | 0.28 | 0.21 |
| Molecular Norms— | | | | | | |
| Qz | 43.9 | 31.2 | 3.7 | 3.7 | 13.6 | 0.0 |
| Or | 7.0 | 19.8 | 3.7 | 3.8 | 24.0 | 40.2 |
| Ab | 15.7 | 12.5 | 0.3 | 23.7 | 30.0 | 40.7 |
| Ne | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.5 |
| An | 12.2 | 5.5 | 39.0 | 29.5 | 15.3 | 6.9 |
| Wo | 0.0 | 0.0 | 20.0 | 4.5 | 1.6 | 0.5 |
| En | 10.4 | 12.1 | 14.2 | 23.8 | 9.1 | 0.0 |
| Fs | 7.3 | 10.4 | 9.8 | 9.3 | 2.6 | 0.0 |
| Fo | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3.3 |
| Fa | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.6 |
| Il | 1.3 | 1.2 | 1.2 | 0.5 | 1.3 | 1.7 |
| Mt | 0.9 | 0.5 | 8.1 | 1.2 | 2.5 | 0.6 |
| Cr | 1.3 | 6.8 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |

1 – Sharpstone conglomerate (Triassic), from upper north slope of Knob Hill.
2 – Rawhide shale (Triassic), 500 metres south of Snowshoe pit in rock cut on main haulage road.
3 – Skarn from southeast corner of Snowshoe pit.
4 – Microdiorite (Jurassic/Cretaceous ?), cutting Triassic beds 1.5 kilometres southeast of Phoenix pit.
5 – Pyroxene-feldspar porphyry (Tertiary), from Observatory Hill 700 metres north of Phoenix pit.
6 – Feldspar porphyry (Tertiary), 500 metres southeast of Phoenix pit.

The base of the sharpstone section in the map-area is apparently a low angle fault at a vertical depth of about 150 metres (*see* diamond-drill hole No. 20, Fig. 1). Here the contact of the conglomerate is marked by fault gouge and crushed grey chert of the basement complex. A similar relationship, obscured somewhat

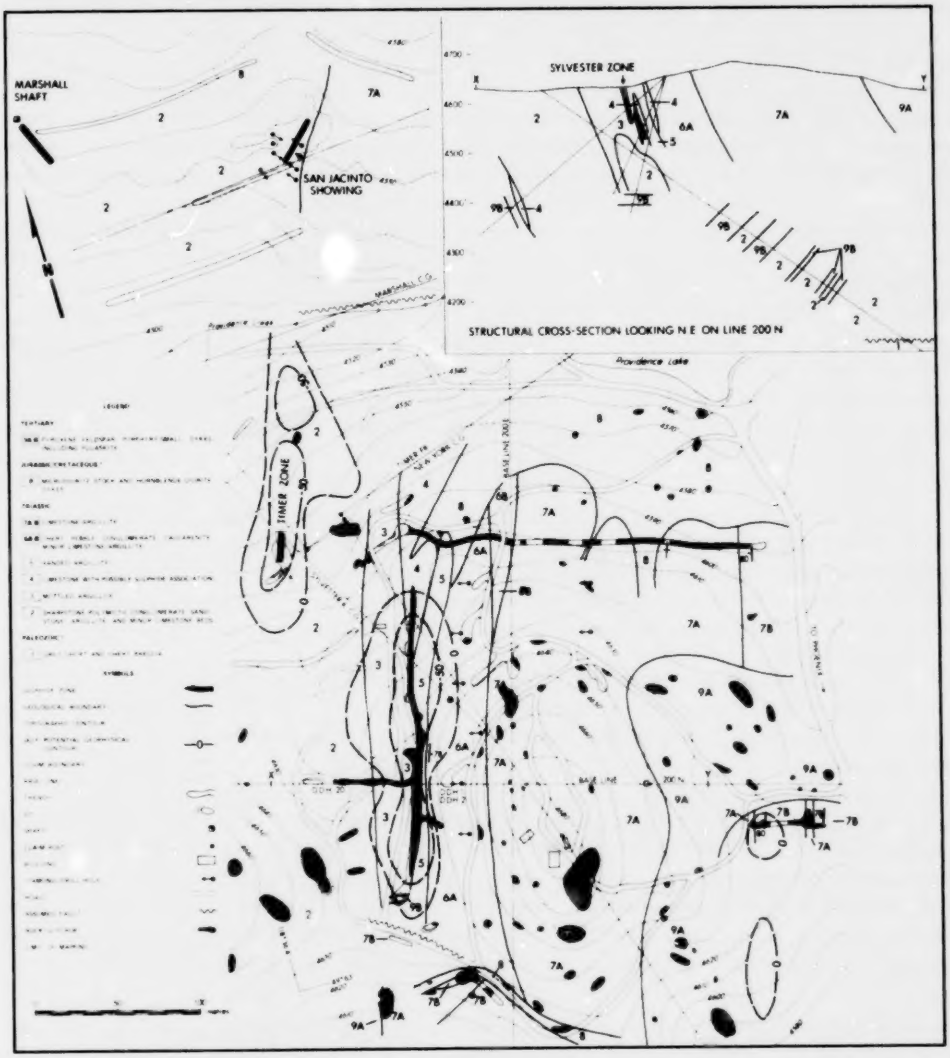

Figure 1. Geology and self-potential survey of the Sylvester 'K' gold-sulphide prospect (82E/2E).

The sharpstone member passes upward into a 60-metre-thick transitional zone of massive argillite with lenses of carbonate, layers of banded argillite and siltstone, and beds of mature sandstone and chert pebble conglomerate with carbonate bands. The argillite of this transition zone may correlate with the 'footwall argillite' of the Phoenix pit.

The Brooklyn limestone member is best exposed in the central and northern part of the map-area. It consists mainly of massive limestone, several hundred metres thick, with some intercalations of argillite such as near the road to Providence Lake by the east boundary of the map-area. East of the map-area, stratigraphic relationships are unclear. There the Brooklyn limestone is apparently succeeded upward by another layer of sharpstone conglomerate, followed in turn by 'Stemwinder' limestone breccia. The Stemwinder is a peculiar, blocky breccia possibly related to a late volcanic episode cogenic with the Upper Triassic Eholt Formation seen near the Oro Denoro mine several kilometres to the east (Church, 1976, p. 4).

## IGNEOUS INTRUSIONS

The main igneous intrusion is an irregular microdiorite stock several hundred metres in diameter exposed just south of Providence Lake. This is a greenish grey rock with a fine, even-grained texture. Thin-section studies show a predominance of rectangular, clay-altered plagioclase cyrstals, 0.5 to 1.5 millimetres in diameter, intermixed with a scattering of chloritized amphibole laths set in a matrix of altered feldspar, ferromagnesian minerals and a minor amount of quartz. Epidote is present in variable amounts, up to 10 per cent, occurring mostly in replacements of the ferromagnesian minerals and the calic cores of some plagioclase crystals.

Porphyritic grey dykes, found scattered widely throughout the map-area, appear to be offshoots of the Providence Lake microdiorite body. These rocks are fine grained with conspicious needle-like prisms of black amphibole 2 to 6 millimetres in length. In thin section, crowded, rectangular, and polygonally zoned plagioclase 0.5 to 1 millimetre across is mixed with subhedral amphibole prisms and glomerophenocrysts of magnetite and amphibole (~15 per cent) in a matrix of altered feldspar, chlorite, magnetite, and epidote.

Other significant microdiorite intrusions lie east of Providence Lake and near Hartford junction, 1.5 kilometres southeast of the Phoenix pit. Chemical analysis of a sample from the Hartford location is given in the accompanying table (No. 4). The age of the microdiorite is believed to be similar to the Greenwood batholith which has been dated by K/Ar methods at 125 to 140 Ma (Church, 1974, p. 49; 1976, p. 5).

Tertiary intrusions include a wide variety of pulaskite, pyroxene, and feldspar porphyry sills and dykes, many of which have been intersected in drilling. These rocks are generally fresh and show little sign of faulting or metamorphism. They follow fractures, are irregular in outline and dip, and commonly change orientation abruptly.

An irregular pyroxene-feldspar porphyry is the largest Tertiary intrusion. It cuts the Brooklyn Formation in the southeast part of the map-area. The rock is brownish with scattered cream-coloured polygonal feldspar phenocrysts and dark green augite subhedra. In thin section, augite (~5 per cent), zoned plagioclase crystals (15 per cent), and glomerophenocrysts, to 4 millimetres in diameter, are set in a matrix of interlocking alkali feldspar, plagioclase, and accessory biotite, quartz, magnetite, and apatite. Chemical analysis of a sample of this rock from the hill east of the map-area is given in the accompanying table (No. 5).

A Tertiary feldspar porphyry intrusion 0.5 kilometre southeast of the Phoenix pit is an alkaline, two-feldspar rock with no visible or normative quartz (*see* analysis No. 6, accompanying table). This dyke-like body intrudes a major gravity fault marking the contact between Early Tertiary sedimentary and volcanic rocks and skarnified sharpstone conglomerate.

## STRUCTURAL GEOLOGY

The area in vicinity of the Phoenix pit and extending beyond Providence Lake and the Sylvester K prospect is an easterly tilted half-graben structure. Vertical displacements ranging to several hundred metres occur on some of the north/south and east/west bounding gravity faults. This structure, which is known to be of Early Tertiary age and has been extensively intruded by Tertiary dykes, is superimposed on folded and faulted rocks of the Brooklyn Formation.

According to Fyles (1982, Assessment Report 10 632, pp. 3-16) early deformation of the Brooklyn strata resulted in formation of an asymmetrical syncline with a vertical northerly trending westerly limb and a gently northwest-dipping easterly limb. The axis of this fold, which plunges 10 to 15 degrees to the north-northeast, passes east of the Sylvester K map-area to be intercepted by the Snowshoe fault north of Providence Lake. The Snowshoe fault is a major southeasterly trending low angle thrust or tear fracture displaced by the Tertiary graben structure.

Important faulting also occurs where the Brooklyn beds are exposed on the steep west limb of the syncline. For example, an east/west-trending left lateral strike slip fault on Providence Creek offsets the sharpstone and limestone contacts approximately 120 metres. Low angle faulting is also revealed by the drill results, where pre-Triassic basement rocks were intercepted at relatively shallow depth.

## MINERALIZATION

Discovery of significant mineralization on the Sylvester K claim was announced by Kettle River Resources Ltd. on October 18, 1982. Backhoe trenching of a strong VLF electromagnetic anomaly revealed a zone of gold-bearing pyrite beneath 3.4 metres of soil and gossan.

Previously, the area seemed unpromising for exploration, except for pyrite in old pits where grab samples assayed as much as 0.26 ounce of gold. The only other encouraging evidence was a private report by W. H. White, dated September 1950, which outlined a copper/zinc biogeochemical anomaly close to the New York Crown-granted claim boundary near the present discovery.

Trenching has revealed a zone of massive sulphides exposed intermittently over a total length of 160 metres. The zone attains a thickness of more than 2.5 metres, dips steeply to the east, and strikes 015 degrees azimuth (*see* Fig. 1 and Plate I). The mineralization appears to be concordant with transitional strata between Brooklyn limestone and sharpstone conglomerate.

The following is a brief description of core from diamond-drill hole No. 6 which is midway on the zone:

| THICKNESS IN METRES DRILL COLLAR | DESCRIPTION |
|---|---|
| >12.0 | Grey sandstone and conglomerate with carbonate matrix – some rust on joints |
| 0.6 | Mottled massive argillite with orbicular structures |
| 3.6 | Light-coloured sandstone and some conglomerate with well-rounded chert pebbles |
| 1.2 | Hornblende porphyry diorite dyke |
| 2.0 | Chert pebble conglomerate with accessory clasts of varied composition |
| 3.0 | Chert sandstone and grit |
| 2.3 | Limestone with many sesame seed-like chert grains |
| 3.0 | Massive grey, silica-rich limestone |
| 0.6 | Hornblende porphyry diorite dyke |
| 5.2 | Banded argillite with a few pyrite bands |
| 1.8 | White hard limestone with mosaic pattern of small cracks |
| 0.6 | Mottled pyritic argillite |
| 1.2 | Calcarenite with thin greenish argillaceous band |
| 3.0 | Zone of massive sulphides (mostly pyrite) with some argillaceous impurities |
| 9.4 | Light brown to grey massive argillite with orbicular structures and many joints with thin seams of pyrite |
| >25.6 | Hornblende porphyry diorite dyke with xenoliths of chert and epidotized argillite |

75.1 metres total thickness of strata in diamond-drill hole No. 6

According to company reports, assay results on the 3-metre intersection of massive sulphide in drill hole No. 6 yielded 11.96 grams per tonne gold. At surface on baseline 200N, sampling across the sulphide zone yielded 5.6 metres assaying 9.12 grams per tonne gold, 7.54 grams per tonne silver, and 0.14 per cent copper. In the same area the footwall argillite assayed 1.99 grams per tonne gold and 3.77 grams per tonne silver across 18.0 metres.

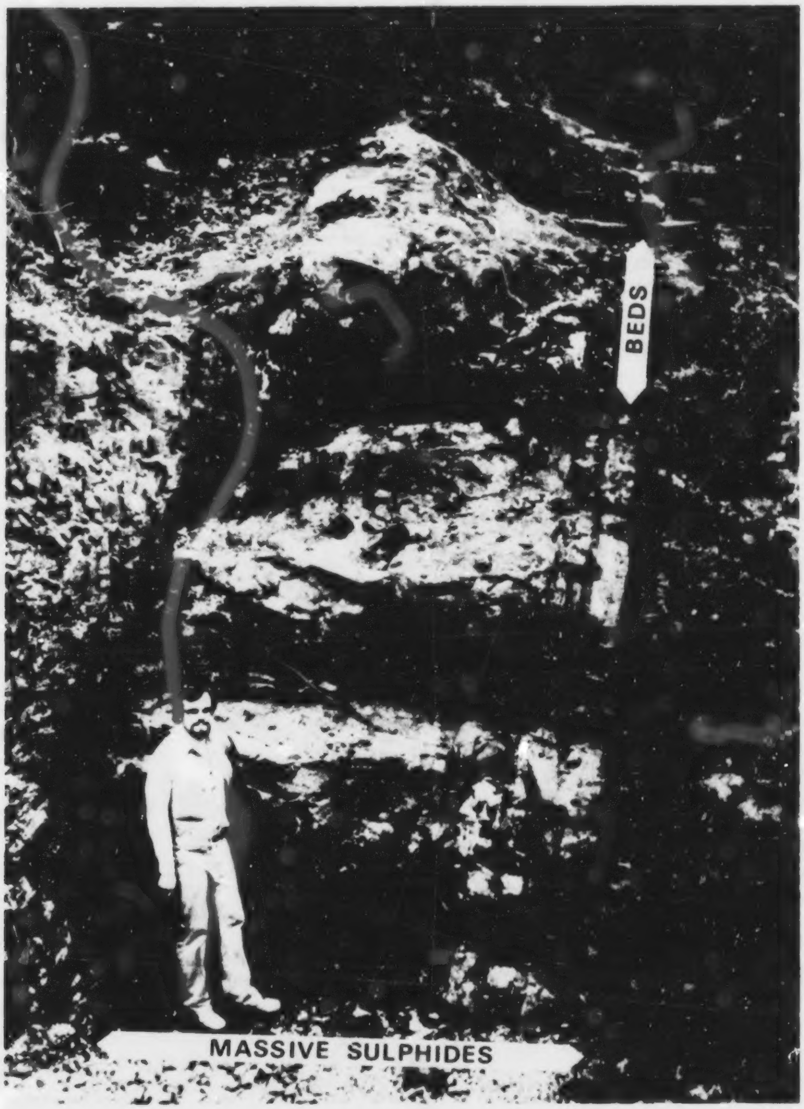

Plate I. Discovery trench on Sylvester K massive sulphide zone.

The mineralogy of the ore zone is simple. Pyrite, the principal sulphide, is accompanied by accessory pyrrhotite and marcasite, and trace amounts of chalcopyrite. In paragenetic sequence, pyrrhotite probably formed early from warm mineralizing solutions and marcasite developed later in a cooler environment.

Gangue minerals include carbonates, quartz, and chlorite. These are intermixed with sulphide grains or interbanded forming lenticular masses.

Secondary alteration by oxidation and groundwater action produced a limonite-goethite cap several metres thick above the ore zone. Trenching of this gossan has revealed peculiar Karst-like cave structures. Rapid oxidation of newly exposed pyrrhotite and marcasite in the trench produces a white powdery coating consisting of a mixture of rozenite and melanterite.

In a similar setting, the San Jacinto sulphide zone, 120 metres west of Providence Lake on the Marshall Crown-granted claim, contains an even wider range of minerals, which includes magnetite, specularite, galena, garnet, epidote, and amphibole.

The targets for mineralization are thin limestone beds in the transition zone, exemplified by the Sylvester K and San Jacinto prospects, and limestone lenses in the sharpstone unit which host the 'Timer' and Marshall shaft prospects. These are classified as calcic exoskarn deposits following the system of Einaudi and Burt (1982). Accordingly, it is theorized that the metasomatic fluids followed the course of the microdiorite dykes into the stratigraphic pile then infiltrated bedding planes. Recrystallization of the carbonate units by these warm fluids produced granular or sugary textures that facilitated further infiltration and eventual wholesale replacement.

The effect of the mineralizing solutions on wallrocks of the ore zone is well displayed on the Sylvester K claim. For example, the footwall argillite on line 200N, which is normally pale green, has been transformed into a light brown fine-grained biotite-bearing hornfels. Here numerous thin pyrite stringers carry gold and silver values for more than 10 metres outward from the massive sulphide zone. In other areas, chlorite and hematite are common on joints and cracks in the host rocks.

Diffusion metasomatism in the argillite is manifest by reaction of the host with carbonate clasts. In this process the clasts are transformed to orbicular or ameboid-shaped structures, 0.5 to 2 centimetres in diameter, with carbonate-epidote cores and tremolite-actinolite rims. The argillite consists of very fine-grained quartz, feldspar, biotite, and small amounts of pyrite and chlorite. In some orbicular structures pyrite has formed in the cores together with calcite and epidote.

The source of the mineralizing solutions is believed, by some Kettle River geologists, to be the microdiorite, although exposures of this rock are small and no significant mineralization is visible south of Providence Lake where it intrudes the Brooklyn limestone. However, considering the wide distribution of microdiorite in the area, including the broad distribution of related dykes, it is possible that the main parent plutonic body lies at depth.

A volcanogenic origin of the mineralization has been considered and dismissed by K. Dawson of the Geological Survey of Canada who visited the area with the writer. The principal lines of evidence arguing against this theory is calc-silicate assocation and textural features pointing to infiltration and replacement by ore solutions. No 'tuff' or 'vent rocks' have been identified with confidence by the writer in the immediate area.

## SELF POTENTIAL SURVEY

A self-potential survey was completed covering the Sylvester K prospect and adjoining areas southwest of Providence Lake. Where the targets are conducting massive sulphide bodies such as the Sylvester K discovery or Phoenix-type deposits, the self-potential geophysical method is known to be a particularly useful exploration tool in delineating buried mineralization.

The survey was performed utilizing an existing cut and chained line grid (50-foot intervals) employing standard procedures, such as fixed electrode configuration including constant connecting wire length, electrode zeroing at base stations, and a base reference station (at grid point 200N, 200E).

The results from 324 stations surveyed show a range of values, mostly between −8 and +39 on the millivolt scale. The lowest readings obtained all coincided with sulphide mineralization:

| PROSPECT | READING |
|---|---|
| Sylvester K | −329 |
| San Jacinto | −215 |
| Timer | −194 |
| Marshall shaft | −262 |

To illustrate the main results, isopotential contours at 0 and −50 millivolt levels were drawn from the grid and superimposed on the geological map (Fig. 1).

The survey shows two northerly trending anomalies which coincide with Sylvester K prospect, in the central part of the map-area, and the Timer zone about 100 metres to the northwest. The Timer anomaly is especially interesting because it suggests buried mineralization extending over a length of about 150 metres, approximately the same size as the Sylvester K prospect. According to company reports, sampling of sulphides from a trench near the south end of the Timer zone yielded assay results ranging to 5.1 grams per tonne gold across a 3-metre width.

On the north, the Timer anomaly points beyond the survey grid area toward the San Jacinto deposit. A connection here would almost double the estimated length of the inferred mineralized zone, however, this projection would transgress local stratigraphy and the Providence Creek fault lineament. Alternatively, the Timer zone might be displaced by faulting about 120 metres to the west, which would result in general alignment with the Marshall shaft prospect. In either case, the self-potential results show that the area holds additional opportunities for exploration.

## ACKNOWLEDGMENTS

Many thanks for assistance in conducting this study are owing officers of Kettle River Resources Ltd., including Dr. J. T. Fyles, G.O.M. Stewart, W. Gilmour, and K. Daughtry. Mr. G. Addie of Nelson was especially helpful in loaning self-potential equipment and offering professional advice on implementing the surveys. Advice and assistance were also rendered by Dr. K. Dawson, metallogenist with the Geological Survey of Canada.

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# THE FARLEIGH LAKE RADIOACTIVE OCCURRENCE
## (82E/5W)

By B. N. Church

## INTRODUCTION

The Farleigh Lake area, 11 kilometres west of Penticton, was a focus of interest and investigation up until the time of the Provincial moratorium on uranium exploration. Work completed to 1980 by Petro Canada Exploration Inc. included 40 kilometres of linecutting on the Astro claim, that was followed by geochemical and geophysical surveys, then a program of diamond drilling. The targets of this activity were radioactive areas in basal Tertiary beds.

## GEOLOGICAL SETTING

The Farleigh Lake area is underlain by an eroded Jurassic-Cretaceous granitic complex that is partly covered by basal Tertiary volcanic and sedimentary rocks. The Kettle River Formation is the oldest Tertiary unit and consists of granite boulder conglomerate, arkose, and rhyolite tuff that unconformably overlies the granite. Disconformably above this are purple and grey volcanic rocks, wackes, and siltstones of the Yellow Lake Member of the Marron Formation. These units are succeeded upward by slightly younger trachytes of the Nimpit Lake Member of the Marron Formation and dacitic lavas and feeder dykes of the Marama Formation (*see* Fig. 2 and accompanying table).

Structurally, the area is relatively simple. The Tertiary beds are inclined gently to the south and southwest, dipping outward from the granite complex, which is exposed in the north and north-central part of the map-area. Important gravity movement occurred east of the Marron Valley fault which slices north-northwest across the eastern part of the map-area. A number of subsidiary faults, marked by minor movement and lineaments, intersect the granite complex and the Tertiary rocks.

## RADIOACTIVE ROCKS

During the course of the geological survey of the map-area, 39 stations were established to measure the radioactivity of the various rock types. This was achieved using a portable gamma ray scintillometer (Geo Metrics/Exploranium Model GRS-101) which yielded the following results:

| ROCK TYPE | MEAN $\overline{X}$ *cps* | STANDARD DEVIATION *cps* | NUMBER OF SAMPLES |
|---|---|---|---|
| Yellow Lake Member | | | |
| Volcanic Rocks | 159 | 30 | 15 |
| Sedimentary Rocks | | | |
| Wacke, shales | 213 | 31 | 4 |
| Pink grit | 300-600 | — | — |
| Kettle River Formation | | | |
| Rhyolite tuff | 100 | 34 | 5 |
| Conglomerate and arkose | 162 | — | 3 |
| Granitoids | 83 | 21 | 12 |

Clearly the most radioactive rocks are the pink grits. These occur as a subunit within wacke-shale lenses intercalated in the Yellow Lake alkaline volcanic assemblage. In the Kettle River Formation, the conglomerates and arkosic beds are more radioactive than the rhyolite tuffs.

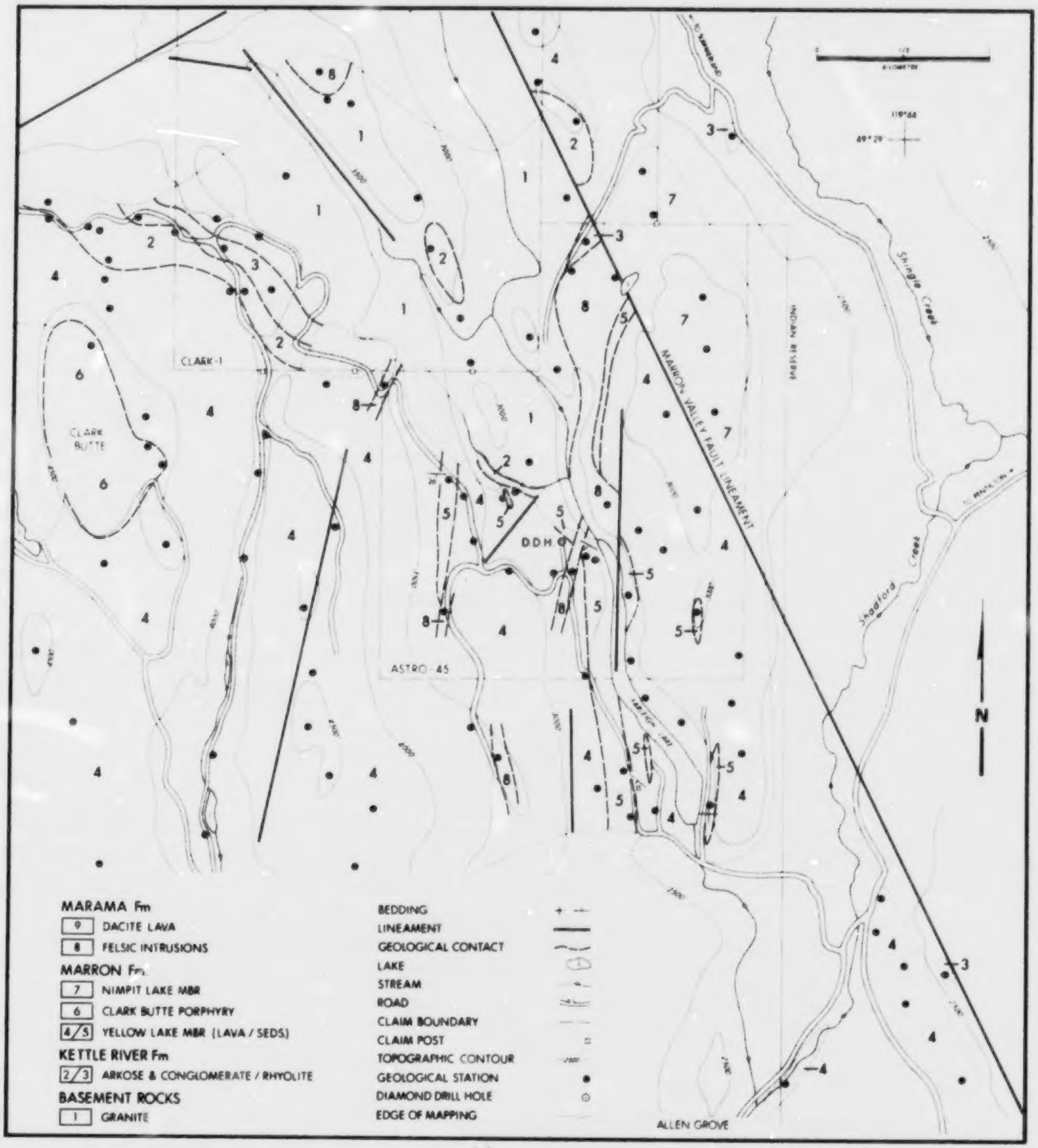

**Figure 2.** The Farleigh Lake radioactive occurrence (82E/5W).

### CHEMICAL ANALYSES OF ROCKS FROM THE FARLEIGH LAKE AREA
### (82E/5W)

| | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Oxides Recalculated to 100– | | | | |
| $SiO_2$ | 76.16 | 62.57 | 56.09 | 58.48 |
| $TiO_2$ | 0.38 | 0.68 | 1.04 | 0.76 |
| $Al_2O_3$ | 16.19 | 18.60 | 16.43 | 20.25 |
| $Fe_2O_3$ | 1.77 | 3.30 | 4.51 | 2.97 |
| FeO | 0.32 | 1.58 | 1.97 | 1.29 |
| MnO | 0.03 | 0.10 | 0.10 | 0.11 |
| MgO | 0.47 | 1.21 | 4.52 | 1.70 |
| CaO | 0.35 | 1.49 | 6.17 | 4.58 |
| $Na_2O$ | 0.58 | 4.52 | 3.84 | 4.42 |
| $K_2O$ | 3.75 | 5.95 | 5.33 | 5.44 |
| | 100.00 | 100.00 | 100.00 | 100.00 |
| Oxides as Determined – | | | | |
| $H_2O+$ | 3.12 | 1.74 | 1.02 | 0.69 |
| $H_2O-$ | 0.26 | 0.38 | 0.48 | 1.06 |
| $CO_2$ | 0.25 | 0.25 | 0.25 | 0.31 |
| S | 0.01 | 0.01 | 0.01 | 0.01 |
| $P_2O_5$ | 0.30 | 0.09 | 0.36 | 0.34 |

Key to Analyses:

1 – Rhyolite tuff breccia from Kettle River Formation, 3 kilometres northwest of Farleigh Lake.

2 – Radioactive tuff, Skaha Creek area.

3 – Mafic phonolite lava from Yellow Lake Member, 400 metres west of south end of Farleigh Lake.

4 – Clarke Butte sill, Yellow Lake Member, 3 kilometres northwest of Farleigh Lake.

Pink grit is best exposed in the section near the Petro-Canada drill hole immediately west of the north end of Farleigh Lake. Here the beds are 30 metres thick. They occur below the lowest mafic phonolite lavas of the Yellow Lake Member and overlie tuffaceous sandstones and siltstones. The grit is well layered, however, it displays few examples of grading, crossbedding, or scour structures. The pink colour of this rock is caused by numerous broken alkali-feldspar crystals and pebbles of feldspathic rhomb porphyry lava. Where the grit is most deeply eroded several tuffaceous layers and a few very thin coal seams, 1 to 3 centimetres thick, are exposed.

In the Petro-Canada drill hole, 200 metres west of the exposed section, the grit diminished in thickness to only 3.8 metres, perhaps indicating that it is a channel deposit. According to company reports, assay results on core yielded an average of 29 ppm uranium and 110 ppm thorium. A single sample from a coal seam gave 65 ppm uranium and 185 ppm thorium. The drill hole intercepted the Kettle River Formation below the Yellow Lake Member. The hole cut 46 metres of rhyolite breccia resting on 29 metres of conglomerate. Although no assay results are available from this core, grab samples elsewhere are encouraging. For example, trenching in the Kettle River conglomerate and arkose by Brinco Mining Limited, immediately south of Brent Lake to the north of the map-area, produced surprising assay results in the range of 1 to 1.5 per cent $U_3O_8$ on samples from a thin carbonaceous seam.

## DISCUSSION

Basal units of the Early Tertiary assemblage are the source of radioactive anomalies and have provided interesting targets for uranium exploration. The pink grit, near the base of the Yellow Lake Member of the Marron Formation, is unusual in that the unit appears to represent a channel deposit of reworked alkaline ash and ash flow material. The source of this material could be the Riddle Creek radioactive volcanic centre several kilometres to the northwest. The boulder conglomerates and arkose of the Kettle River Formation are more in keeping with the 'basal uranium' model where the metal source is the underlying granitoid complex. In the future the Penticton area may provide a unique opportunity for investigation of these two diverse, yet spatially related, uranium-thorium occurrences.

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# DISCUSSION OF TILLICUM MOUNTAIN SELF–POTENTIAL TEST SURVEYS TO DATE

## (82F/13)

**By G. G. Addie**

## INTRODUCTION

The first self-potential (SP) survey was made at Tillicum Mountain on August 22, 1980 with the discoverers Arnold and Elaine Gustafson. At that time a strong SP anomaly was noted at the 'Money Pit' – the source of the first high-grade gold samples. Over the next three years further surveys were undertaken in an attempt to either identify extensions of the 'Money Pit' or to find new 'ore' zones (Fig. 3). Results of the first survey were published in *Geological Fieldwork, 1981* (Kwong and Addie, 1982). In this case the 'short wire' or 'relative potential' method using a 200-metre wire with stations every 5 metres was used. Finally in 1983 the long-wire method (200 metres) was used (Burr, 1982). Because of the experimental nature of our surveys none of the lines have been closed; therefore the amount of error is not known.

## 1983 SELF–POTENTIAL RESULTS

This year the survey was run along a road which cuts across the geological boundaries (Fig. 3). Three SP anomalies were encountered; in all cases argillite is present.

## OBSERVATIONS AND RECOMMENDATIONS

Both the 'Money Pit' and the 'Jennie Zone' have argillite contacts. Whether these are on the same argillite layer remains to be proven; folding of the sedimentary rocks is suspected. Solution of the structural problems could be greatly assisted by further SP work to trace argillite layers. Some of this argillite carries significant mineralization as indicated by the following assays from grab samples at the 522-millivolt SP anomaly on the road east of the 'Money Pit' (Fig. 3):

| SAMPLE NO. | Au *ppm* | Ag *ppm* | Cu *ppm* | Pb *ppm* | Zn *per cent* | As *per cent* | WIDTH *metres* |
|---|---|---|---|---|---|---|---|
| 27869M | 3.4 | 10 | 192 | 800 | 0.44 | 0.3 | 5 (FW) |
| 27870M | 0.3 | 10 | 162 | 56 | 0.35 | 0.15 | 3 (HW) |

NOTE: A check assay using the 'reject' from sample 27869M ran 6.5 ppm gold, confirming the gold content. Because of the erratic gold assays free gold is suspected.

## CONCLUSIONS

(1) The SP survey method has been successful in identifying three anomalies in argillite.

(2) Both the 'Money Pit' and the 'Jennie Zone' mineralization have footwall argillites; it is not known whether they are the same argillite.

(3) Argillite samples at the 522-millivolt SP anomaly has a significant gold content which should be verified by detailed sampling.

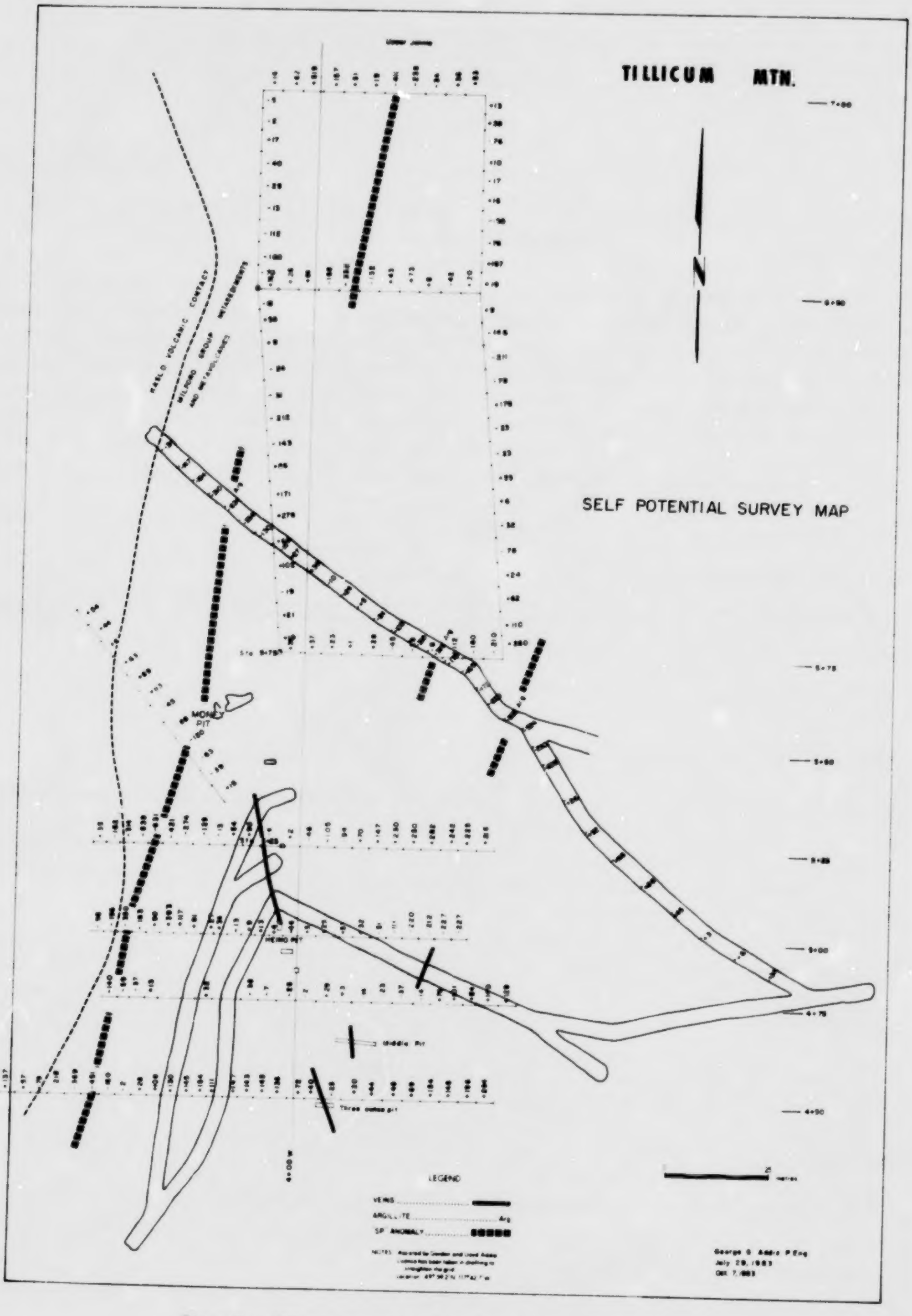

Figure 3. Tillicum Mountain self-potential survey map (82F/13).

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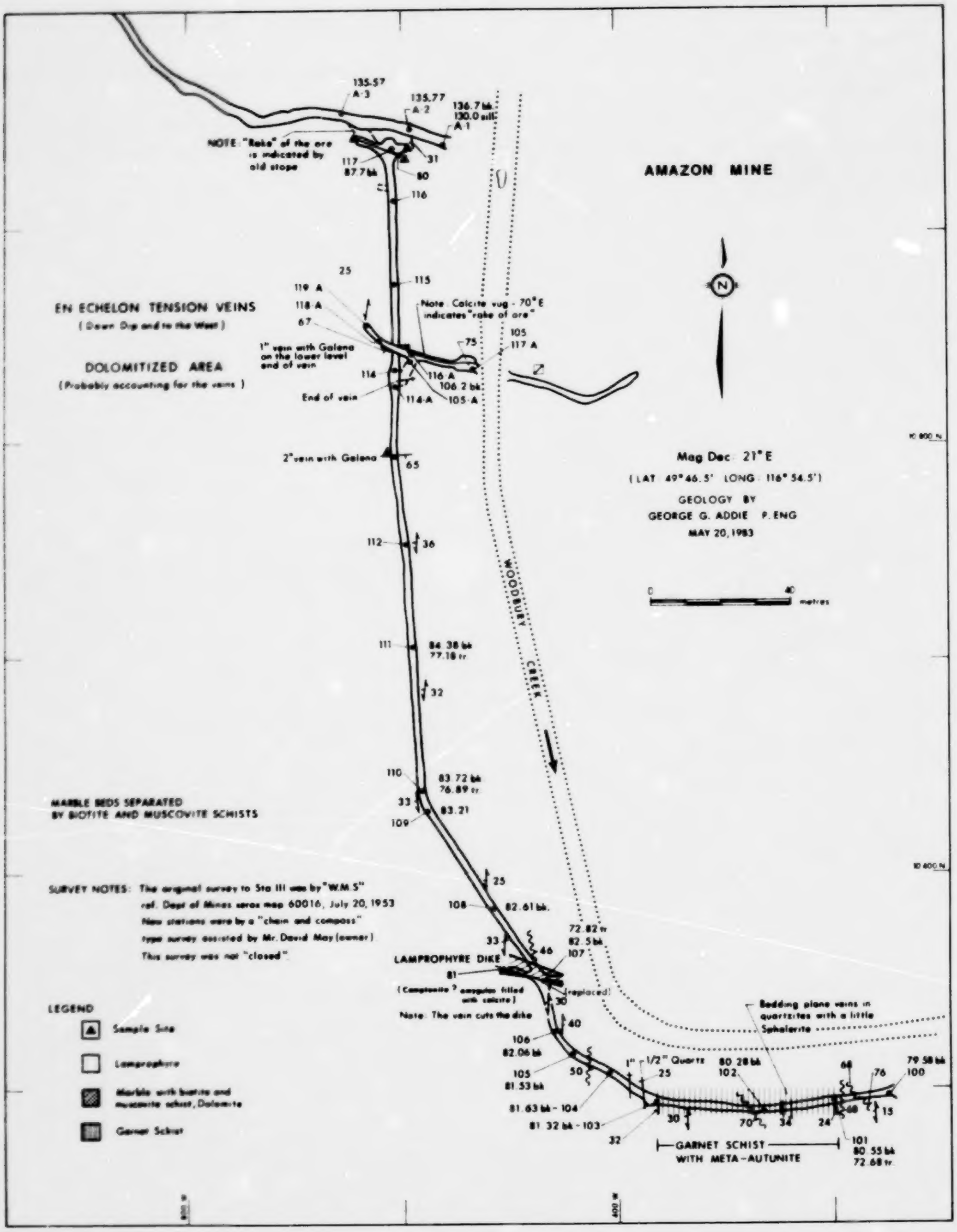
AMAZON MINE
N
135.57
A-3
135.77
A-2
136.7 bk.
130.0 sill
A-1
NOTE: "Rake" of the ore is indicated by old stope
117
87.7 bk.
31
80
116
25
115
119 A
118-A
67
EN ECHELON TENSION VEINS
(Down Dip and to the West)
Note: Calcite vug - 70°E indicates "rake of ore"
105
117 A
75
1" vein with Galena on the lower level end of vein
DOLOMITIZED AREA
(Probably accounting for the veins)
114
116-A
106.2 bk.
End of vein
114-A
105-A
2" vein with Galena
65
Mag Dec: 21° E
(LAT: 49° 46.5' LONG: 116° 54.5')
GEOLOGY BY
GEORGE G. ADDIE P. ENG
MAY 20, 1983
10 800 N
112
36
WOODBURY CREEK
0
40
metres
111
84.38 bk
77.18 tr.
32
110
83.72 bk
76.89 tr.
33
109
83.21
MARBLE BEDS SEPARATED
BY BIOTITE AND MUSCOVITE SCHISTS
10 600 N
SURVEY NOTES: The original survey to Sta III was by "W.M.S"
ref. Dept of Mines xerox map 60016, July 20, 1953
New stations were by a "chain and compass"
type survey assisted by Mr. David May (owner)
This survey was not "closed".
25
108
82.61 bk.
33
46
72.82 tr
82.5 bk
107
LAMPROPHYRE DIKE
81
(Camptonite ? amygules filled with calcite)
(replaced)
Note: The vein cuts the dike
30
40
LEGEND
▲ Sample Site
☐ Lamprophyre
▨ Marble with biotite and muscovite schist, Dolomite
▥ Garnet Schist
106
82.06 bk
105
81.53 bk
50
81.63 bk - 104
81.32 bk - 103
32
1"
1/2" Quartz
25
30
80.28 bk
102
Bedding plane veins in quartzites with a little Sphalerite
70
34
68
24
68
76
15
79.58 bk
100
101
80.55 bk
72.68 tr.
GARNET SCHIST
WITH META-AUTUNITE
600 W
400 W

Figure 4. Amazon mine (Ainsworth Mining Camp) (82F/15).

# AMAZON MINE (AINSWORTH MINING CAMP)
# (82F/15)

**By G. G. Addie**

## GENERAL

The Amazon mine (Mineral Inventory 82F/NE-7) has been converted to an excellent mining museum by Mr. David May. The only map available of the mine was a partial map signed 'W.M.S.' dated July 20, 1953. We completed this survey using the 'Road Runner Underground Survey' method; a one-man survey procedure with the same accuracy as the traditional chain and compass method (Fig. 4).

## GEOLOGY

The geology of the area and the Amazon mine is well described by Fyles in Bulletin 53 (1967). Stratigraphically the mineralization is in dolomitized Lardeau Group metamorphic rocks (Middle Cambrian to Ordovician in age). The intrusions (lamprophyre) and veins are believed to be Tertiary. The extent of dolomitization is not known. The presence of tin in the assays suggests a genetic association with granite. Perhaps a magnetic anomaly on the east side of Woodbury Creek represents a subsurface granitic plug. If so, this area should be prospected for vein and replacement deposits.

We only have four observations to add to the description of Fyles (1973):

(1) The veins are tension veins.
(2) The rake of the 'ore' is suspected to be steeply to the southeast as defined by a stope.
(3) The veins are post-lamprophyry (believed to be Tertiary in age).
(4) The garnet schist contains meta-autunite.

## ASSAYS

| Laboratory No. | Submitters Mark | *ppm* Au | Ag | *Per Cent* Pb | Zn | Location | |
|---|---|---|---|---|---|---|---|
| 27600M* | 051083–1 | <0.3 | <10 | 0.38 | 2.92 | 10310N | 505W |
| 27601M | –2 | <0.3 | <10 | 1.25 | 2.83 | 11085N | 642W |
| 27602M | –3 | <0.3 | <10 | 350 ppm | 4.57 | 11075N | 597W |
| 27603M | –4 | <0.3 | <10 | 450 ppm | 700 ppm | 11070N | 600W |
| 27604M* | 051283 | <0.3 | 85 | 10.5 | 3.8 | 11790N | 610W |

*Sn = 0.3 per cent

## REFERENCE

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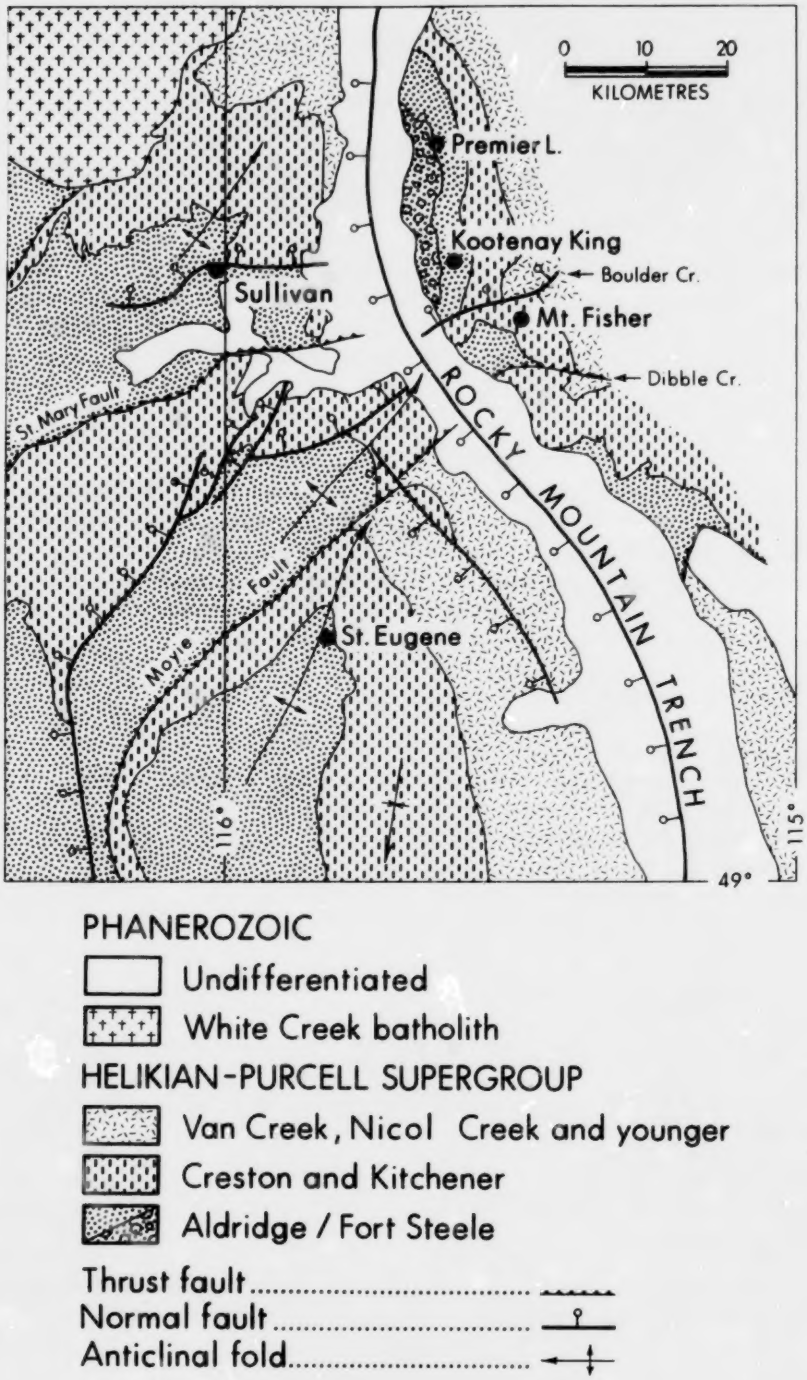

Figure 5. Regional geological map showing location of Sullivan deposit.

# STRUCTURAL SETTING, MINERAL DEPOSITS, AND ASSOCIATED ALTERATION AND MAGMATISM SULLIVAN CAMP, SOUTHEASTERN BRITISH COLUMBIA

# (82F, G)

By T. Höy

## INTRODUCTION

The Sullivan deposit is a large, essentially stratiform lead-zinc-silver orebody in late Proterozoic Aldridge Formation turbidites in southeastern British Columbia. It is located near the eastern margin of the Purcell anticlinorium, just west of the Rocky Mountain Trench (Fig. 5). It has been the focus of a number of recent studies, including its geology (Hamilton, *et al.*, 1982, 1983; Hamilton, in press), structure (McClay, 1983), alteration (Shaw, in preparation), and isotopic signature (Nesbitt, *et al.*, 1982; Campbell, *et al.*, 1978). Recently regional geology in the vicinity of the deposit has been described by Höy (1983), based on fieldwork in 1982 and previously published maps by Schofield (1915), Rice (1937), and Leech (1958, 1960).

The purpose of this paper is to describe in more detail geology in the immediate vicinity of the Sullivan mine. The report focusses on the structural setting of Sullivan and describes a regional Sullivan 'camp' alteration zone. As well, evidence is presented which suggests that the thick accumulation of Moyie gabbroic sills within the Aldridge Formation is a magmatic event in Lower Aldridge and early Middle Aldridge time, in part prior to lithification of the sedimentary pile, rather than a post-lithification intrusive event.

## STRUCTURE

The structure in the vicinity of the Sullivan deposit is dominated by two prominent fault sets that cut shallow-plunging broad open folds. Sullivan-type faults trend north to northeasterly (Fig. 6), dip steeply to the west, and generally have normal, west-side-down offsets of a few tens of metres (faults a, b, c, d, Fig. 7) (Hamilton, *et al.*, 1983; McClay, 1983). Those east of the deposit (c, d) are drawn schematically; they may in fact involve cumulative movements on a number of smaller northeast-trending faults as shown on Figure 2.4 of Hamilton, *et al.* (1983). Sullivan-type faults cut a number of east-west-trending, north-dipping faults. The most prominent of these, the Kimberley fault, cuts the north fringes of the Sullivan deposit at depth (Hamilton, personal communication, 1983). It has an apparent net normal displacement of at least 2 500 metres (Hamilton, *et al.*, 1982; McClay, 1983) and juxtaposes Creston Formation rocks against Middle and Lower Aldridge rocks (Fig. 6).

A steep, generally west-dipping cleavage is prominent throughout the area. The cleavage is widely spaced (approximately 5 centimetres) in competent quartz wacke beds, is more closely spaced in siltites, and locally comprises a penetrative foliation in phyllite (near the southwest corner of the map-area, *see* Fig. 6). The cleavage is axial planar to broad, generally open folds (illustrated in the sections of Fig. 7). Southwest of Sullivan on North Star Hill (domain 1, Fig. 8), folds are locally tight with fold hinges that plunge variably to the north or south. In general, however, bedding is relatively flat lying to east dipping, cleavage dips steeply west, and bedding/cleavage intersections plunge at low angles to the north or south, parallel to fold hinges. In the Sullivan mine area (domain 2, Fig. 8), regional bedding is also relatively flat lying to east dipping, cleavage dips variably to the west, and cleavage/bedding intersections and fold axes, although

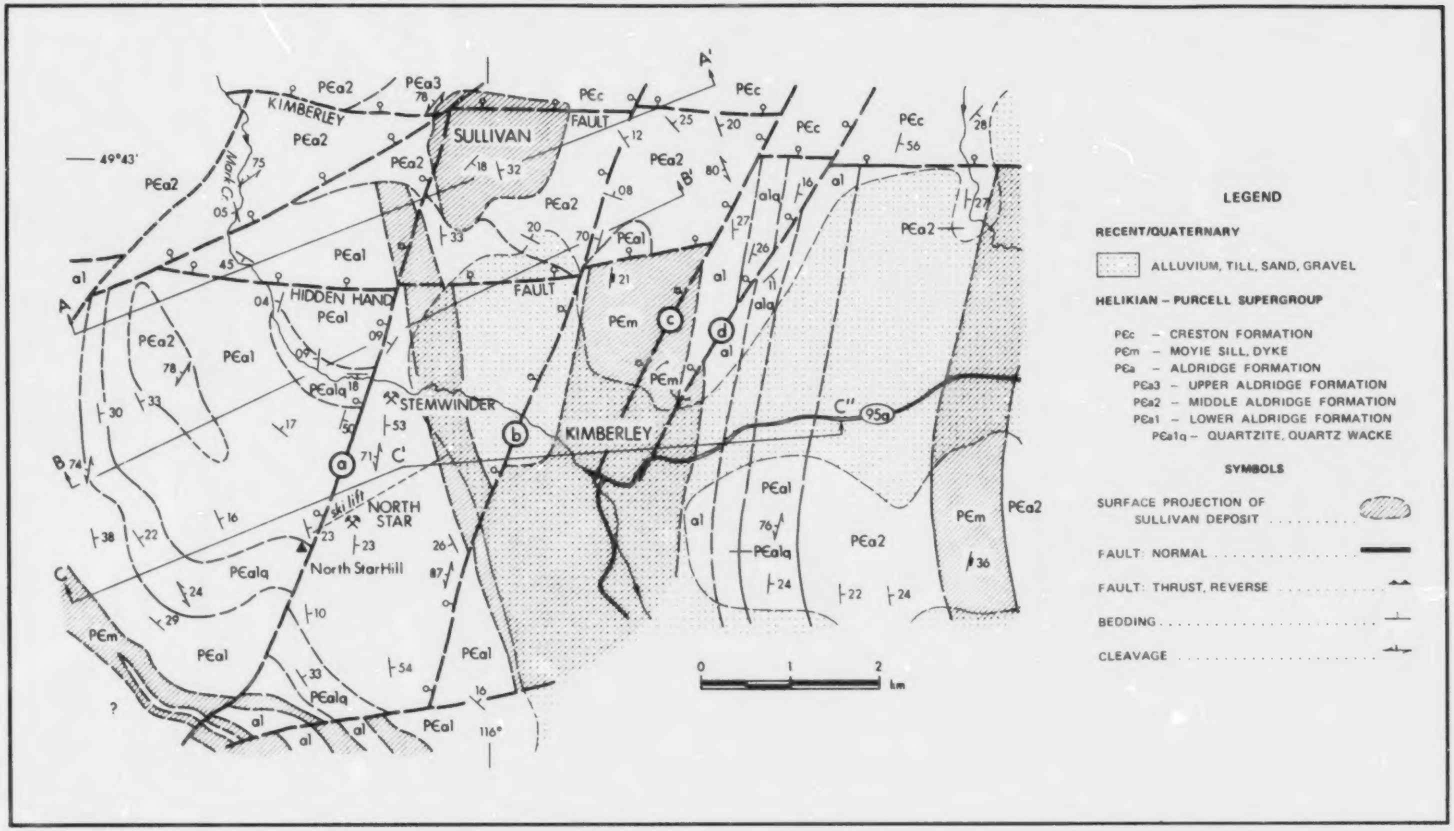

Figure 6. Geology in the vicinity of the Sullivan deposit, Kimberley.

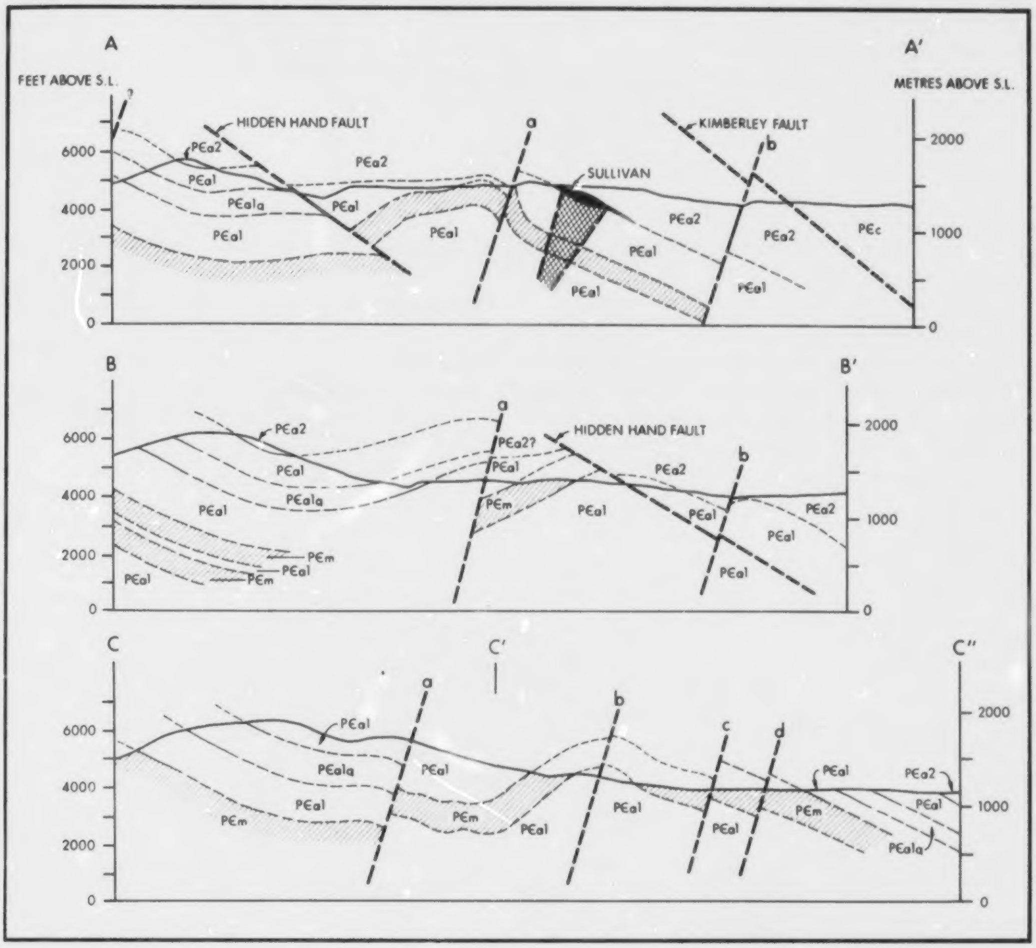

Figure 7. Vertical structural sections, Sullivan deposit area; *see* Figure 6 for locations.

scattered, generally trend north-northeasterly or south-southwesterly; plunges are up to a few tens of degrees. These folds and associated cleavage are correlative with Phase 2 structures described by McClay (1983) in the Sullivan deposit. The greater scatter of structural elements in the deposit is undoubtedly because of lower competency of the thinly laminated sulphides (compare Fig. 17 of McClay with domain 2 of Fig. 8). East of the Sullivan deposit and in the Concentrator Hill area (domain 3, Fig. 8) bedding trends north and dips 20 to 30 degrees east. Cleavage dips steeply west-northwest; lineations and bedding/cleavage intersections plunge at low angles to the north-northeast.

A late crenulation cleavage locally overprints the pronounced regional fold and associated cleavage.

Regional fold deformation in the Kimberley-Cranbrook area is dominated by large, open to locally tight folds that verge eastward; they are probably related to west-dipping thrust faults and associated east-trending tear faults. These structures deform and offset Paleozoic rocks but appear to predate Late Cretaceous granite bodies (Höy, 1983), and are, therefore, probably related to the regional Mesozoic orogeny as suggested by McClay (1983).

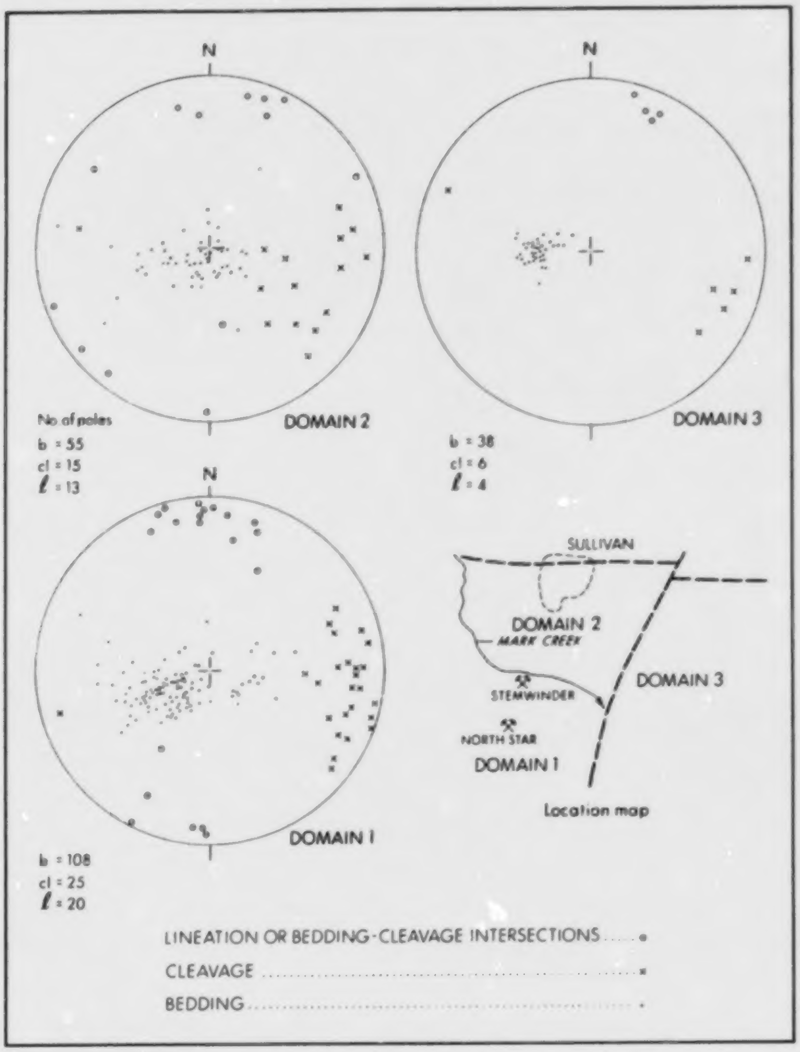

**Figure 8.** Equal area projections of structural data, Sullivan deposit area.

## PURCELL SUPERGROUP STRATIGRAPHY

The Purcell succession in the Kimberley area has been described recently by Hamilton, *et al.* (1983) and Höy (1983); it will be reviewed only briefly here. Within the thick succession of rusty weathering, generally laminated siltite and argillite of the Lower Aldridge Formation is a 250-metre-thick sequence of grey-weathering quartz wacke and quartz arenite beds (unit PЄalq) that is lithologically similar to the basal part of the Middle Aldridge Formation. This unit crops out on the western and southern slopes of North Star Hill and on the western slope of Concentrator Hill (Fig. 6). The sequence, where exposed in Mark Creek, is more rusty weathering and somewhat thinner bedded. The Lower Aldridge grades up section into grey-weathering quartz wacke, quartz arenite, and more rusty weathering laminated siltite of the Middle Aldridge Formation (unit PЄa2). The Lower/Middle Aldridge transition is poorly exposed. Where outcrop allows, it has been placed below the first appearance of prominent blocky, grey-weathering quartz wacke beds.

The Upper Aldridge Formation consists of approximately 300 metres of rusty to dark-grey-weathering laminated argillite and silty argillite. The Creston Formation (PЄc) is composed of grey, green, or mauve-coloured siltite and quartzite with numerous shallow water subtidal to intertidal sedimentary structures.

## MINERAL DEPOSITS

The Sullivan deposit, and a number of smaller stratabound lead-zinc-silver deposits, occur in a north-northwest-trending regional alteration zone that extends from Sullivan southward to North Star Hill.

The Sullivan deposit is one of the largest base metal deposits in the world; it has produced 116 million tonnes of ore grading 6.7 per cent lead, 5.8 per cent zinc, and 79 grams silver per tonne. Remaining reserves are approximately 45 million tonnes containing 4.5 per cent lead, 6.0 per cent zinc, and 38 grams silver per tonne. Its geology has been described recently by Hamilton, *et al.* (1982, 1983). In brief, the deposit is a large, generally conformable lens of massive pyrrhotite, galena, and sphalerite that lies near the top of the Lower Aldridge Formation. Its western part, comprising generally massive to irregularly layered sulphides, overlies a brecciated and tourmalinized footwall alteration zone (Fig. 9); the orebody is overlain by an albite-chlorite-pyrite-carbonate alteration halo. Its eastern part consists of a number of thinly laminated sulphide layers separated by fine-grained clastic rocks.

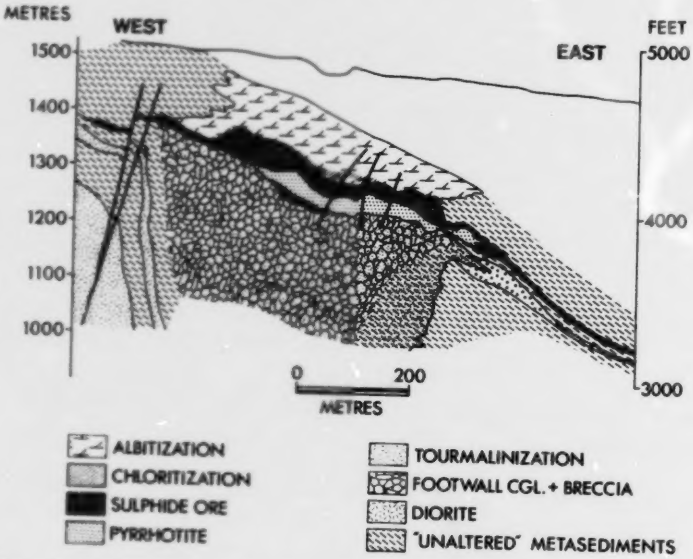

Figure 9. Schematic vertical section through the Sullivan deposit (simplified from Hamilton, *et al.*, 1982).

Numerous small vein occurrences, a few thin stratabound sulphide lenses, and a number of larger stratabound deposits occur within a few kilometres south of Sullivan. The North Star deposit, located approximately 4 kilometres south-southwest of Sullivan (Fig. 6), is a small, but very high-grade, stratiform deposit in Lower Aldridge siltstones. The deposit produced 70 000 tonnes of hand-sorted material containing 46 per cent lead, less than 1 per cent zinc, and about 1 000 grams silver per tonne (Hamilton, *et al.*, 1983, p. 45). It is described (Schofield, 1915) as a conformable lens of massive galena only partly preserved in synformal structures on the eastern slopes of North Star Hill. Construction of the North Star ski hill complex has largely covered the old workings.

The Stemwinder is located between Sullivan and North Star. It produced approximately 25 000 tonnes containing 3.7 per cent lead, 15.6 per cent zinc, and 76.3 grams silver per tonne. Reserves include approximately 125 tonnes of 82 grams per tonne silver, 3 per cent lead, and 16 per cent zinc (Hamilton, *et al.*, 1983, p. 45). The deposit trends northerly and dips steeply west. It is interpreted to be a vein deposit that occurs in a tight, faulted synclinal structure (Freeze, 1966).

## REGIONAL ALTERATION IN THE SULLIVAN CAMP

Lead-zinc-silver deposits in the Sullivan camp are enclosed within a north-northeast-trending zone of intensely altered Lower Aldridge siltstone and quartzite. The zone is approximately 6 000 metres in length, 1 500 to 2 000 metres wide, and locally, beneath the Sullivan deposit (Hamilton, 1983), extends through a known stratigraphic interval of at least 500 metres. On North Star Hill tourmalinized rock was intersected in drill holes to depths exceeding 200 metres (D. H. Olson, personal communication). The alteration zone appears to be restricted to Lower Aldridge rocks; that is, rocks that stratigraphically underlie the Sullivan deposit. It is characterized by:

(1) A marked increase in the abundance of disseminated and irregularly laminated pyrrhotite and, to a lesser extent, pyrite. Surface exposures are typically highly oxidized.

(2) An increase in the number of pyrite, galena, and sphalerite-bearing veins.

(3) An increase in the number of 'massive' sulphide occurrences, such as North Star, Stemwinder, and a number of other smaller occurrences.

(4) Zones of pervasive tourmalinized and silicified rock, similar to those described in the footwall of the Sullivan deposit. These alteration zones are commonly irregular in outline with either sharp or gradational contacts; they cross lithologic boundaries. Locally, thin tourmaline-rich laminations occur in siltstone. The tourmalinite is a dark, hard siliceous rock that breaks with a conchoidal fracture.

(5) Irregular zones of breccia or 'conglomerate'. The conglomerate is generally diamictite with subrounded siltite clasts up to 2 centimetres in diameter supported by a siltstone matrix. Pyrite and pyrrhotite with minor amounts of sphalerite and galena typically occur in the matrix. Often, the conglomerate grades into massive (lacking bedding) siltstone or quartzite. The conglomerates may define beds but can form clastic dykes. Similar rocks in the footwall of the Sullivan, termed 'fragmentals' are interpreted to have formed by injection and local surface extrusion, rather than by collapse of fault scarps (Hamilton, in press).

(6) Obliteration of bedding by intense sulphide alteration, tourmalinization, silicification, or development of 'conglomerate'.

Many of these features extend beyond the limits of the intense alteration zone described previously. For example, thin laminations of tourmalinite occur 3 to 4 kilometres south of the North Star deposit in Lower Aldridge siltite, and a crosscutting conglomerate occurs on a small hill nearby (A. Hagen, personal communication, 1980). As well, anomalous numbers of sulphide laminae occur at the Lower/Middle Aldridge transition (Sullivan horizon) on Concentrator Hill, which is 5 kilometres east of North Star Hill.

## MOYIE INTRUSIVE ROCKS – A PRELITHIFICATION MAGMATIC EVENT ?

Laterally extensive sills, which are predominantly gabbroic in composition (accompanying table), intrude the Lower and the lower part of the Middle Aldridge Formation. They are generally a few tens to several hundred metres thick, with medium to coarse-grained equigranular central parts and finer grained margins. A thin hornfelsic zone occurs adjacent to some sill contacts. Locally, Moyie intrusions also form dykes. Although Moyie intrusions have isotopic ages indistinguishable from the host Aldridge rocks (approximately

1433 Ma, Zartman, *et al.*, 1982), it has generally been accepted that they are coeval with deposition of the Upper Aldridge Formation or Creston rocks (Zartman, *et al.*, 1982), or perhaps with Nicol Creek lavas (McMechan, 1981). However, Höy (in press) suggested that they are early and were emplaced into water-saturated Aldridge sediments a few tens to a few hundreds of metres below the sediment surface. If this is correct, the Moyie sills may be evidence of a regional igneous/thermal event during deposition of Lower to Middle Aldridge rocks, hence during formation of contained stratiform sulphide deposits. A modern example of intrusion of basaltic sills into highly porous unconsolidated turbidite sediments was described by Einsele, *et al.* (1980) from drill sites in the Guaymas Basin, Gulf of California.

Moyie sills have a number of features in common with Guaymas Basin sills: they are basaltic in composition (accompanying table; Fig. 10), intrude turbidites, and occur in a basin formed by rifting (*see* Sears and Price, 1978; Price, 1981). Intrusion of 2 000 to 3 000 metres of Moyie sills (*see* Reesor, 1958; Höy and Diakow, 1982) into lithified Aldridge rocks could only be accommodated if there were considerable uplift of the surface rocks; no such uplift is evident in post-Aldridge time. If it occurred, major unconformities or coarse clastics would be apparent in the overlying succession of dominantly platformal rocks. Room is not a problem if the sills were injected into unconsolidated, water-saturated sediments; expulsion of pore fluids results in little change in relief of the sea floor (Einsele, *et al.*, 1980). Crosscutting, sheeted fracture zones containing calcite-epidote-chlorite-quartz and, locally, sulphide assemblages and vein concentrations near sill margins are common in Moyie sills. These may be evidence of hydrothermal activity associated with water expulsion and escape through the sills. Transgressive zones of disrupted bedding, such as occurs on Highway 3 at the south end of Moyie Lake, could be large dewatering structures associated with sill injection. Perhaps the best direct evidence that some sills were injected into wet, unconsolidated sediments are local development of flame and load cast structures at the base of some Moyie sills (Plate II); similar structures have been observed by Dave Pighan (personal communication, 1983). As well, a thin (20 to 30-centimetre) contact zone with large hornblende crystals is common at the base of some sills; this suggests hydrothermal growth in a mixed magma-crystal-sediment mush. Other sill contacts have fine-grained chilled margins and hornfelsic country rocks, suggesting intrusion into cool, lithified rocks.

Many of the Moyie sills are alkaline basalts (Fig. 10). Magmatism was essentially restricted to early Aldridge and early Middle Aldridge time, dying out in late Middle Aldridge time at the same time as the volume of coarse turbidites decreased. Their abundance, volume, composition, spatial, and suggested temporal restriction to a stratigraphic interval dominated by turbidite deposition suggests that Lower Aldridge and early Middle Aldridge sedimentation took place during a period of continental rifting.

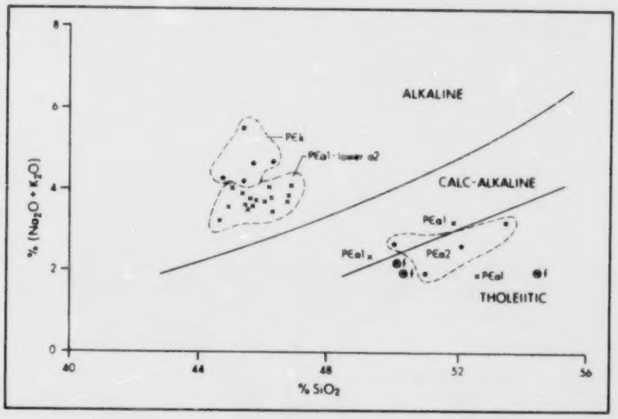

Figure 10. Alkali-silica plot of Moyie gabbroic sills in the Lower Aldridge (PЄa1), Middle Aldridge (PЄa2), and Fort Steele (f) Formations. A number of sills in younger Kitchener Formation (PЄk) are also plotted.

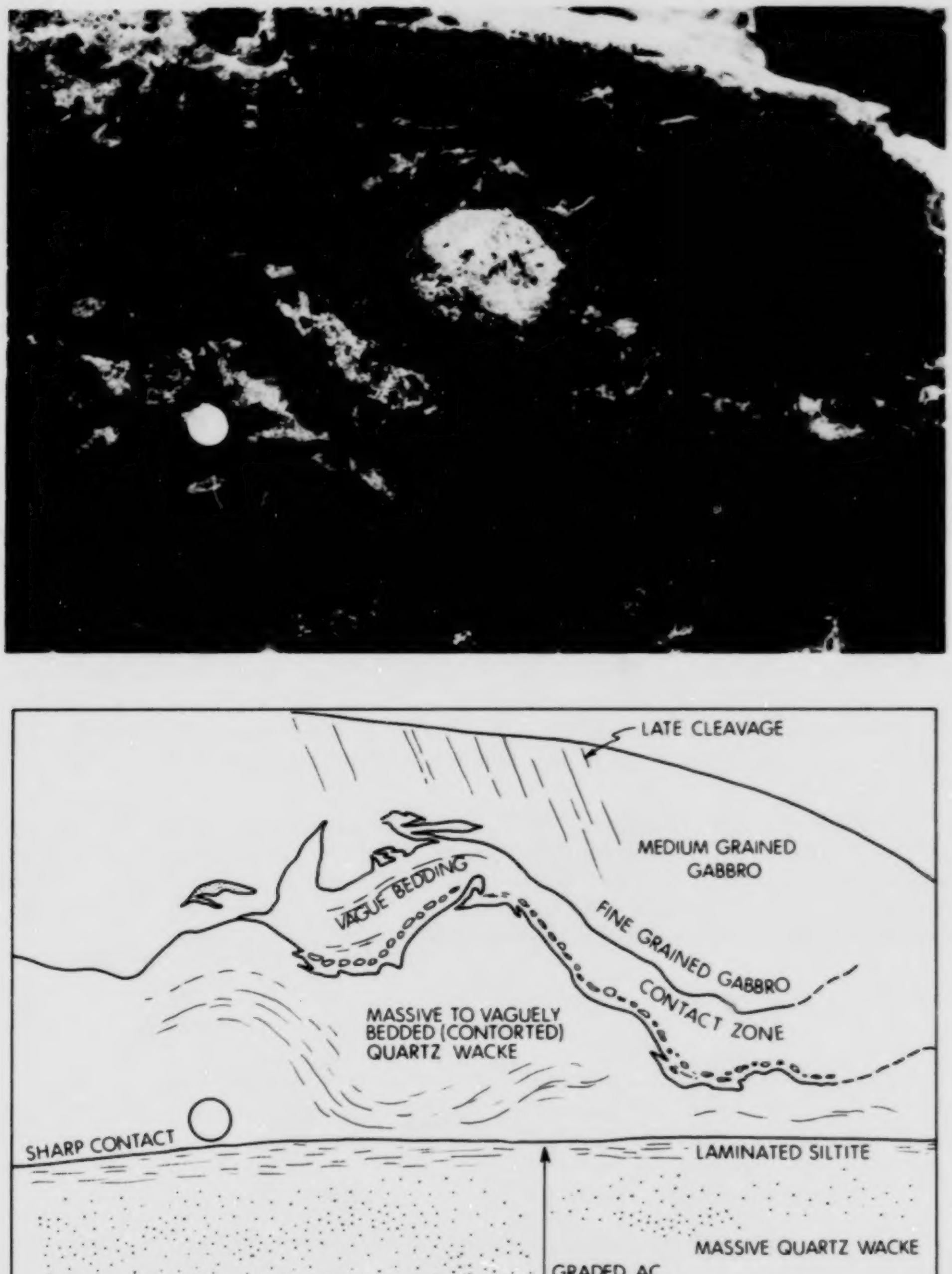

Plate II. Detail of Moyie sill-Middle Aldridge Formation turbidite contact; note features which suggest that the sill was injected prior to lithification of the quartz wacke, such as flame and load cast structures at the base of the sill, and a mixed sediment — coarse-grained hornblende contact zone.

## SILICATE ANALYSES OF MOYIE SILLS IN ALDRIDGE AND FORT STEELE FORMATIONS

| SAMPLE | $SiO_2$ | $Al_2O_3$ | $Fe_2O_{3T}$ | MgO | CaO | $Na_2O$ | $K_2O$ | $TiO_2$ | MnO |
|---|---|---|---|---|---|---|---|---|---|
| M 1–7 | 50.80 | 14.63 | 9.55 | 8.25 | 11.98 | 1.549 | 0.322 | 0.739 | 0.152 |
| | | | | | | | | | |
| M20–1 | 50.05 | 15.94 | 14.67 | 5.02 | 10.06 | 2.439 | 0.227 | 1.108 | 0.201 |
| | | | | | | | | | |
| E8–15 | 53.46 | 14.39 | 9.83 | 8.03 | 2.88 | 2.430 | 0.815 | 0.948 | 0.113 |
| E75–2 | 52.04 | 13.49 | 11.32 | 6.83 | 6.40 | 2.176 | 0.461 | 0.844 | 0.141 |
| | | | | | | | | | |
| M7–209 | 46.82 | 13.77 | 16,62 | 5.51 | 9.07 | 2.952 | 1.115 | 2.606 | 0.259 |
| M7–214 | 46.15 | 13.96 | 16.56 | 5.49 | 10.55 | 2.746 | 0.711 | 2.758 | 0.249 |
| M7–218 | 46.68 | 13.49 | 16.62 | 5.52 | 9.77 | 2.889 | 0.823 | 2.607 | 0.258 |
| M7–223 | 46.72 | 13.76 | 16.18 | 5.35 | 9.85 | 2.925 | 0.934 | 2.628 | 0.252 |
| M7–228 | 45.95 | 13.33 | 16.68 | 5.65 | 9.54 | 2.786 | 0.970 | 2.713 | 0.257 |
| M7–233 | 46.17 | 13.48 | 16.24 | 5.61 | 9.67 | 2.709 | 1.078 | 2.603 | 0.257 |
| M7–240 | 44.94 | 13.81 | 17.05 | 5.65 | 10.25 | 2.660 | 0.968 | 2.854 | 0.265 |
| M7–241 | 45.64 | 13.67 | 16.88 | 5.51 | 9.93 | 2.768 | 0.846 | 2.831 | 0.268 |
| M7–249 | 45.50 | 13.49 | 16.74 | 5.47 | 9.80 | 2.797 | 0.801 | 2.746 | 0.267 |
| M7–251 | 45.57 | 13.48 | 17.00 | 5.49 | 10.04 | 2.841 | 0.924 | 2.791 | 0.270 |
| M7–256 | 46.05 | 13.36 | 16.64 | 5.35 | 9.23 | 2.602 | 1.496 | 2.775 | 0.262 |
| M7–261 | 44.88 | 13.55 | 17.17 | 5.37 | 9.93 | 2.839 | 0.753 | 2.831 | 0.296 |
| M7–265 | 44.66 | 13.12 | 17.48 | 5.28 | 10.25 | 2.750 | 0.469 | 2.729 | 0.280 |
| M7–270 | 44.99 | 13.68 | 17.67 | 5.27 | 8.14 | 3.208 | 0.782 | 2.789 | 0.282 |
| | | | | | | | | | |
| M12–27 | 49.25 | 16.53 | 9.11 | 8.33 | 10.54 | 1.406 | 0.992 | 0.627 | 0.166 |
| M14–15 | 60.02 | 13.28 | 12.18 | 0.97 | 4.86 | 3.069 | 2.045 | 1.312 | 0.187 |
| | | | | | | | | | |
| K23–2 | 51.87 | 14.23 | 8.88 | 7.74 | 9.93 | 1.476 | 1.795 | 0.625 | 0.149 |
| K38–4 | 61.04 | 11.55 | 6.09 | 2.64 | 7.87 | 4.254 | 4.484 | 0.199 | 0.320 |
| | | | | | | | | | |
| D3–7A | 43.87 | 14.36 | 12.12 | 6.73 | 10.42 | 2.196 | 2.753 | 2.535 | 0.199 |
| E4–1 | 54.40 | 13.98 | 11.32 | 6.44 | 10.96 | 1.435 | 0.687 | 0.736 | 0.180 |
| E6–1 | 50.08 | 14.62 | 12.62 | 9.55 | 2.79 | 0.263 | 2.000 | 1.167 | 0.141 |
| E55–4 | 50.30 | 14.53 | 9.52 | 8.13 | 11.43 | 1.562 | 0.429 | 0.690 | 0.154 |

Sample M1–7 – in Middle Aldridge Formation, sheet 82G/5 (Moyie).
Sample M20–1 – in Middle Aldridge Formation, sheet 82G/4 (Yahk).
Samples E8–15 and E75–2 – in Middle Aldridge Formation, sheet 82G/12E, 13E.
Samples M7–209 to M7–270 – in Middle to Lower Aldridge transition, sheet 82G/4 (Yahk).
Samples M12–22 and M14–15 – in Lower Aldridge Formation, sheet 82G/5 (Moyie).
Samples K23–2 and K38–4 – in Lower Aldridge Formation, sheet 82G/12 (Cranbrook).
Samples D3–7A to E55–4 – in Fort Steele Formation, sheets 82G/12E, 13E.

## DISCUSSION

The Sullivan and other smaller stratabound lead-zinc-silver deposits in the Sullivan camp presumably formed by venting of hydrothermal, metal-charged brines onto the sea floor. The deposits occur within a broad area of intense alteration that is restricted to the Lower Aldridge Formation. This suggests that initially a thermal convective cell was operative over a wide area with local well-established discharge points; later it became more localized and in late Lower Aldridge time it formed the Sullivan deposit. The hydrothermal system continued to be active after sulphide deposition ceased; it caused chlorite-pyrite alteration of the central part of the Sullivan massive sulphide lens and albite-chlorite-pyrite-carbonate alteration of overlying Middle Aldridge sediments (Hamilton, *et al.*, 1983).

It is suggested that intrusion of Moyie sills was, at least in part, contemporaneous with deposition of Aldridge turbidites and contained stratiform base metal deposits. It is unlikely that these sills supplied a substantial magmatic component to the source hydrothermal fluids, or that they directly provided a heat source to drive a convective cell. Their presence does, however, indicate an elevated geothermal gradient, and the associated thick accumulation of turbidites probably reflects contemporaneous tectonic activity in the form of crustal extension. Movements on deep-rooted basement faults have been documented in Aldridge rocks just east of the trench (Höy, 1982; in press). This tectonic activity, concentrated near the intersection of a north-trending rifted continental margin (Price, 1981) with a pronounced southwest-trending tectonic zone (Kanasewich, 1968; Höy, 1982), both triggered and localized a thermal convective cell system.

Through Middle Aldridge time, as the Purcell basin was being filled, the rate of turbidite deposition and gabbroic sill intrusion decreased, indicating waning tectonic and magmatic activity. Local tourmalinite and 'conglomerate' occurrences in Middle Aldridge rocks indicate, however, that faulting, rock fracturing, and convective systems continued on a local scale. By Upper Aldridge time only dark fine-grained silts and muds were being deposited, indicating relatively stable tectonic conditions.

## ACKNOWLEDGMENTS

This report is based on fieldwork during 1982 and 1983. The assistance of M. Fournier and I. Webster is gratefully acknowledged. Discussions with Cominco Ltd.'s geologists, G. D. Delaney, A. Hagen, J. M. Hamilton, D. Pighan, and P. W. Ransom; with L. Diakow of the University of Western Ontario; and with K. R. McClay of Goldsmiths College, London, England, are much appreciated. Part of the geological map (Fig. 6) is taken largely from published maps by Hamilton, *et al.* (1982, 1983); details of the geology of North Star Hill were improved considerably by incorporating studies and notes of R. E. Gale and D. H. Olson of Asarco Exploration Company of Canada Limited. The paper was improved by comments and suggestions of Don MacIntyre, British Columbia Ministry of Energy, Mines and Petroleum Resources.

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# TONSTEINS: POSSIBLE STRATIGRAPHIC CORRELATION AIDS IN EAST KOOTENAY COALFIELDS

## (82G/15, 82J/2)

By D. A. Grieve

## INTRODUCTION

Tonsteins are kaolinitic fine-grained sedimentary rocks associated with coal and coal-bearing strata; they are superficially similar to the shale partings found in most coal seams. Tonsteins are normally thin, but often have considerable areal extent, a factor which has made them extremely useful as correlation tools in many coalfields.

The term 'tonstein' does not, strictly speaking, imply any particular mode of formation. Much recent work suggests that many tonsteins are the end product of the reworking and/or alteration of volcanic ash (for example, Price and Duff, 1969; also *see* paper by Kilby, this volume). Work is at present too preliminary to allow genetic classification of the samples from southeast British Columbia discussed here.

Presence of tonsteins in the Balmer (No. 10) seam in the Sparwood area was reported by Mériaux (1972). During reconnaissance mapping in the south half of the Elk Valley Coalfield (Grieve, 1982; Grieve and Fraser, 1983), samples were taken of unusual-looking argillaceous partings from several coal seams. Thin-section and X-ray diffraction analysis of one example from the Ewin Pass property revealed a texture and mineralogy consistent with tonstein lithologies.

As a follow-up it was decided to test the local continuity of two of the discoveries to assess the potential of using tonsteins for regional stratigraphic correlation in the East Kootenay Coalfields. The current lack of known regionally extensive marker horizons in the coalfields is a problem to geologists in exploration and mining; this was an incentive for conducting this study.

Coal rights in the study area are held by Crows Nest Resources Ltd.

## SAMPLE LOCATIONS

**EWIN PASS:** The Ewin Pass property is approximately 7 kilometres north of Line Creek (Fig. 11). The 1981 discovery of a tonstein (identification number 81-217) in 7(?) seam was made in the bank of a now-reclaimed exploration road (between lines 1200N and 1300N on the company grid). At the time a complete section of the coal-bearing Mist Mountain Formation was measured, which included this same exposure (*see* Grieve, 1982, Fig. 2). For this follow-up study, a new partial section was measured approximately 1 400 metres to the north, on an open, east-facing slope. The section measured is believed, from both the author's and the company geologists' detailed mapping, to correspond to the interval between 8 seam and 5 seam (local nomenclature only). Corresponding portions of both sections are plotted on Figure 12. A tonstein occurs in a coal seam at the same relative stratigraphic position (identification number 83-10). No other tonsteins were noted.

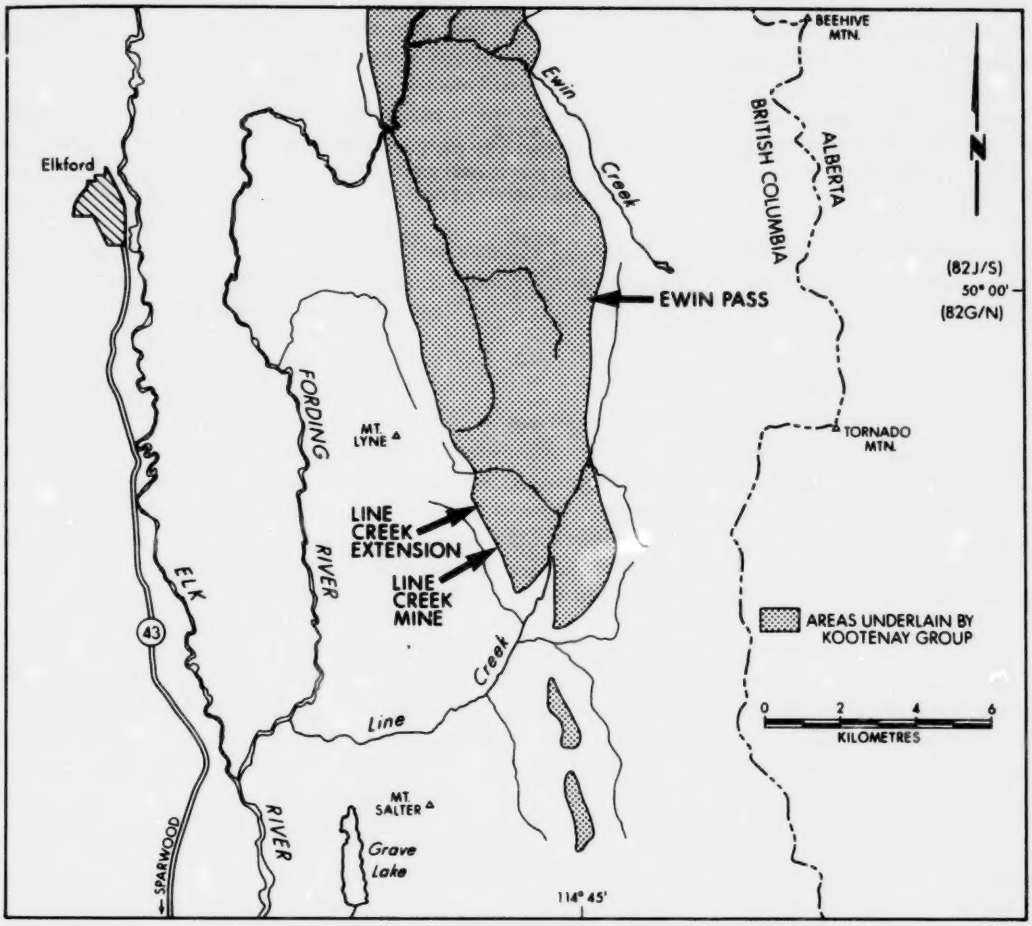


Figure 11. Line Creek area, Elk Valley Coalfield.

**LINE CREEK RIDGE:** Line Creek Ridge is the site of Crows Nest Resources' Line Creek mine, and its so-called Line Creek Extension property (Fig. 11). A closely spaced pair of tonsteins was found at an adit site in 10B seam on the Line Creek Extension (identification number 82-146). A nearly identical pair also occurs at the same stratigraphic level in the high-wall of Line Creek mine, 1.4 kilometres to the south (identification number 83-18B). At the mine two other tonsteins were noted, one overlying the double band by 140 centimetres and the other underlying by 15 centimetres. They are not included in the following descriptions and discussion.

## DESCRIPTION OF SAMPLES

Thickness of the Ewin Pass tonsteins (numbers 81-217 and 83-10) averages 5 to 6 centimetres. Their colour is brownish black, with irregular dark brown patches; streak is also brown. They are very fine grained with visible, light grey rounded blebs (up to 0.5 millimetre) scattered randomly throughout. Lack of laminations or internal partings and two well-developed, closely spaced sets of fractures, both perpendicular to bedding, make these rocks distinctive. The fractures impart a distinctive blocky appearance in outcrop and float. Some of the samples display a conchoidal breakage fracture.

## TABLE 1
## TRACE ELEMENT CONTENT (%) OF LINE CREEK AREA TONSTEIN SAMPLES (SEMIQUANTITATIVE)

| | 81-217 | 83-10 | 82-146 | 83-18B |
|---|---|---|---|---|
| Li | --- | Trace | --- | --- |
| B | Trace | Trace | Trace | Trace |
| P | >>3.0 | >5.0 | Trace | Trace |
| Sc | --- | --- | Trace | Trace |
| Ti | 0.35 | 0.2 | 0.4 | 1.7 |
| V | Trace | --- | Trace | Trace |
| Cr | Trace | --- | Trace | --- |
| Mn | --- | Trace | Trace | Trace |
| Co | --- | --- | --- | 0.007 |
| Ni | --- | --- | --- | 0.006 |
| Cu | Trace | Trace | Trace | Trace |
| Zn | --- | --- | --- | Trace |
| Ga | Trace | Trace | Trace | Trace |
| Sr | 0.5 | 0.5 | Trace | Trace |
| Y | Trace | Trace | Trace | Trace |
| Zr | Trace | Trace | --- | --- |
| Mo | --- | --- | --- | Trace |
| Ag | --- | --- | --- | Trace |
| Ba | 0.75 | >2.0 | <0.05 | <0.05 |
| La | 0.01 | --- | --- | --- |
| Ce | --- | --- | --- | Trace |
| Yb | Trace | Trace | Trace | Trace |
| W | --- | --- | Trace | --- |
| Pb | 0.04 | Trace | Trace | Trace |

## TABLE 2
## OXIDE ANALYSIS OF EWIN PASS TONSTEIN
### (81-217)

| | *Per Cent* |
|---|---|
| $SiO_2$ | 35.52 |
| $Al_2O_3$ | 34.45 |
| $Fe_2O_3$ | <0.10 |
| FeO | <0.3 |
| MgO | <0.05 |
| CaO | 0.22 |
| $Na_2O$ | <0.02 |
| $K_2O$ | <0.03 |
| $TiO_2$ | 1.020 |
| MnO | <0.002 |
| Total $H_2O$ | 14.38 |
| S | 0.09 |
| $P_2O_5$ | 4.5 |
| SrO | >0.5 |
| BaO | >0.5 |
| $CO_2$ | 9.09 |

The two bands in the Line Creek Extension locality (number 82-146) are separated by 1.2 centimetres of dark grey, very fine-grained carbonaceous rock. The lower tonstein, which is 1.2 centimetres thick, is medium brown with black carbonaceous stringers; it has a white streak. It is very fine grained and has two regular sets of fractures, similar to those in Ewin Pass samples. Some fracture planes have a vitreous lustre. Rounded light grey blebs up to 2 millimetres in size are concentrated near the contacts of the band, and also occur in the enclosing 4 to 5 millimetres of dark grey carbonaceous rock. The band is very difficult to physically separate from its enclosing rock. The upper band is 5 millimetres thick, is medium brownish grey, and has a white streak.

The pair of tonstein bands in Line Creek mine high-wall (number 83-18B) are separated by 1 centimetre of carbonaceous rock. The lower brown band is 1 centimetre in thickness, but in all other respects is identical to the corresponding unit described previously.

## PETROGRAPHY OF SAMPLES

Petrographic examinations were necessarily supplemented by X-ray diffraction analyses. Both Ewin Pass samples are characterized by a microcrystalline groundmass of gorceixite [$BaAl_3(PO_4)_2(OH)_5 \cdot H_2O$] with or without kaolinite, with thin stringers of organic material, and with minor amounts of euhedral apatite crystals. Irregular subrounded ovoid bodies of microsrystalline kaolinite containing minor amounts of gorceixite, known as 'graupen', occur throughout. Their long axes generally lie in the bedding plane. In hand specimen the graupen form light grey blebs. Some of the kaolinite in the graupen is in vermicular form.

Only the lower brown band from the Line Creek Ridge samples was examined. Microcrystalline kaolinite forms the groundmass; it is cut by stringers of organic matter and carries angular to subrounded apatite clasts, rare euhedral apatite crystals, and subangular quartz clasts. Many of the quartz clasts have diffuse, corroded outlines. Sample 83-18B also has rare plagioclase (?) laths. Graupen with highly irregular outlines are most abundant near the margins of the band. They are composed of microcrystalline kaolinite, some of which is vermicular. The organic stringers bend around the graupen.

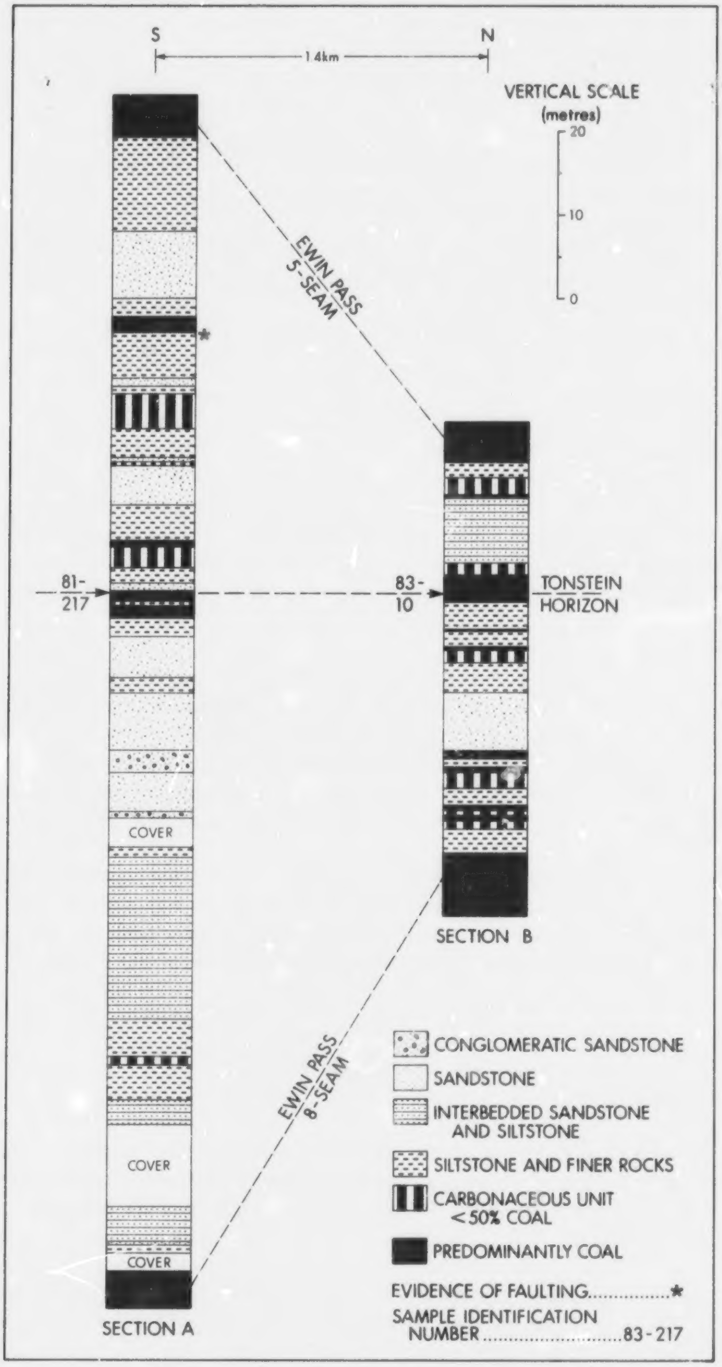
Contact with the enclosing dark rock is sharp; it is marked by the sudden occurrence of thick stringers of organic material (liptinite ?) separated by elongated, flattened graupen and kaolinitic groundmass material. This corresponds with observations in hand specimen that graupen occur both within the brown band and in the enclosing rock, and that the brown band is very difficult to physically separate from its immediate enclosing rock.

## CHEMISTRY OF SAMPLES

Semiquantitative emission spectrographic trace element analyses of four samples are listed in Table 1; an oxide analysis of 81-217 is given in Table 2. Notably all have high titanium values (0.2 to 1.7 per cent). Trace amounts of boron, copper, gallium, yttrium, ytterbium, and lead are also common to all samples analysed.

Relatively higher values of phosphorus and barium in the Ewin Pass samples reflect the mineral gorceixite; perhaps it also accounts for relatively high strontium contents (assuming some solid solution between gorceixite and goyazite [$SrAl_3(PO_4)_2(OH)_5 \cdot H_2O$].

Trace zirconium is restricted to the Ewin Pass samples, while trace scandium is restricted to the Line Creek Ridge samples. Analyses were semiquantitative; these values may not be significant.



S
N
1.4km
VERTICAL SCALE
(metres)
20
10
0
EWIN PASS
5-SEAM
81-
217
83-
10
TONSTEIN
HORIZON
COVER
COVER
COVER
SECTION A
SECTION B
EWIN PASS
8-SEAM
CONGLOMERATIC SANDSTONE
SANDSTONE
INTERBEDDED SANDSTONE AND SILTSTONE
SILTSTONE AND FINER ROCKS
CARBONACEOUS UNIT <50% COAL
PREDOMINANTLY COAL
EVIDENCE OF FAULTING...............*
SAMPLE IDENTIFICATION NUMBER..........................83-217

Figure 12. Detailed stratigraphic sections from two locations on Ewin Pass property showing mapped correlations of 5 seam and 8 seam and proposed correlation of tonstein horizon.

Other elements detected include lithium, vanadium, chromium, manganese, cobalt, zinc, molybdenum, silver, lanthanum, cerium, and tungsten.

## DISCUSSION

Preliminary work suggests that tonsteins have potential as stratigraphic correlation tools in the East Kootenay Coalfields. The occurrence of a double band of tonsteins with very similar characteristics at the same relative stratigraphic level at both Line Creek Ridge and Line Creek Extension is impressive evidence for at least local lateral persistence of the tonsteins; further it demonstrates the utility of simple macroscopic parameters, such as colour, thickness, and grouping of bands. On the Ewin Pass property, discovery of a tonstein at the same relative stratigraphic position at two locations emphasizes the potential of tonsteins to aid in stratigraphic correlation. The proposed correlation is reinforced by the presence of gorceixite at both locations.

In both cases cited a certain amount of stratigraphic control was utilized in deciding where to search for second occurrences of the tonsteins. On a regional scale, where stratigraphic control is often non-existent, petrographic and chemical criteria may prove to be key elements in identification and correlation of specific tonsteins.

As an aside, the marked contrast in thicknesses of the two 8-seam to 5-seam intervals measured on Ewin Pass (Fig. 12) mainly results from facies changes. Faulting recognized in the area of the more southerly section (one zone was noted) may also occur in covered intervals and account for some of this difference. For correlation under such geological conditions the need for reliable regional markers, like tonsteins, is great. Further work will be directed toward determining abundance, regional extent, composition, and origin of tonsteins in the East Kootenay Coalfields.

## ACKNOWLEDGMENTS

Crows Nest Resources' staff gave permission to visit their properties. P. Gilmar (of the company) conducted the author to the sample site in Line Creek mine. In the Ministry, Laboratory Scientist J. Kwong provided advice on interpretation of X-ray diffraction results, and discussions with Project Geologist W. Kilby were very beneficial.

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# HARRISON LAKE PROJECT
## (92H/5, 12; 92G/9)

By G. E. Ray
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and
S. Coombe and G. White
**Rhyolite Resources Inc.**

## INTRODUCTION

The northwest-trending Harrison Lake fracture system, approximately 100 kilometres east-northeast of Vancouver, is associated with regional hot spring activity and sporadic gold mineralization. Most of this gold was found before the turn of the century; it includes numerous occurrences and several small producers such as the Providence (Mineral Inventory 92H/NW-30) and RN (Mineral Inventory 92H/SW-92) mines. Since the 1930's, extensive parts of the Harrison Lake area have not experienced much exploration activity or regional geological mapping.

In 1981-1982 Rhyolite Resources Inc. started drilling some gold-bearing quartz-sulphide veins at Doctors Point, on the western shore of Harrison Lake. The results of this work led to a large staking rush, as some companies realized that areas adjacent to the Harrison Lake fracture system had favourable potential for both epithermal and mesothermal gold mineralization. Part of this activity involved the re-evaluation of some former mines and occurrences in the area; this included work by Abo Oil Corporation on the disused RN gold mine (also known as the 'Geo' occurrence, Mineral Inventory 92H/SW-92), situated approximately 4 kilometres northeast of Harrison Hot Springs.

The current British Columbia Ministry of Energy, Mines and Petroleum Resources' project was initiated in response to the widespread exploration interest in the area. The project involved the following:

(1) Geological mapping at a scale of 1:5 000 of a 3-square-kilometre area in the Doctors Point vicinity (Fig. 13). This mapped area includes all the surface mineralized gold showings discovered and drilled to date by Rhyolite Resources Inc.

(2) Sampling the mineralized veins and unmineralized host rocks for precious metal assaying, whole rock and trace element analyses, and thin-section studies.

(3) Geologically mapping the immediate vicinity of the disused Providence mine (Mineral Inventory 92H/NW-30) at a scale of 1:1 000 (Fig. 16). This included detailed mapping of the main (No. 3) adit on the property (Fig. 17) and collecting mineralized and host rock samples for analyses and thin-section examination.

(4) Reconnaissance geological mapping at a scale of 1:25 000 of the area between the Providence mine and Doctors Point.

(5) A brief examination and sampling of the disused RN gold mine (Mineral Inventory 92H/SW-92) which is currently being re-evaluated by Abo Oil Corporation.

## REGIONAL GEOLOGY

The Harrison Lake fracture system forms a major, southeasterly trending dislocation over 100 kilometres in length, which in parts passes along, and parallel to, Harrison Lake. The system separates highly contrasting geological regimes (Roddick, 1965; Monger, 1970). To the northeast, the rocks include well-deformed supracrustals of the Pennsylvanian to Permian Chilliwack Group (Monger, 1966), as well as highly foliated gneissic rocks and some younger granites. By contrast, the rocks on the southwestern side of the fracture are generally younger, are less deformed, and have suffered lower metamorphic grade; they include a variety of volcanic, volcaniclastic, and sedimentary rocks, as well as intrusive granitic rocks and migmatites. These supracrustals are separable into a number of different groups of Jurassic/Cretaceous age. The most important regarding gold mineralization are the Fire Lake and Harrison Lake Groups which are well developed respectively northwest and southwest of Harrison Lake. The Fire Lake Group (Roddick, 1965) comprises a variety of coarse to fine-grained sedimentary rocks with lesser greenstone volcanic rocks, while the Harrison Lake Group (Crickmay, 1925; Roddick, 1965) is predominantly a volcanic sequence of andesitic to dacitic composition, with lesser amounts of volcaniclastic and sedimentary rocks. Both groups are intruded by younger plutonic rocks ranging from granite to diorite.

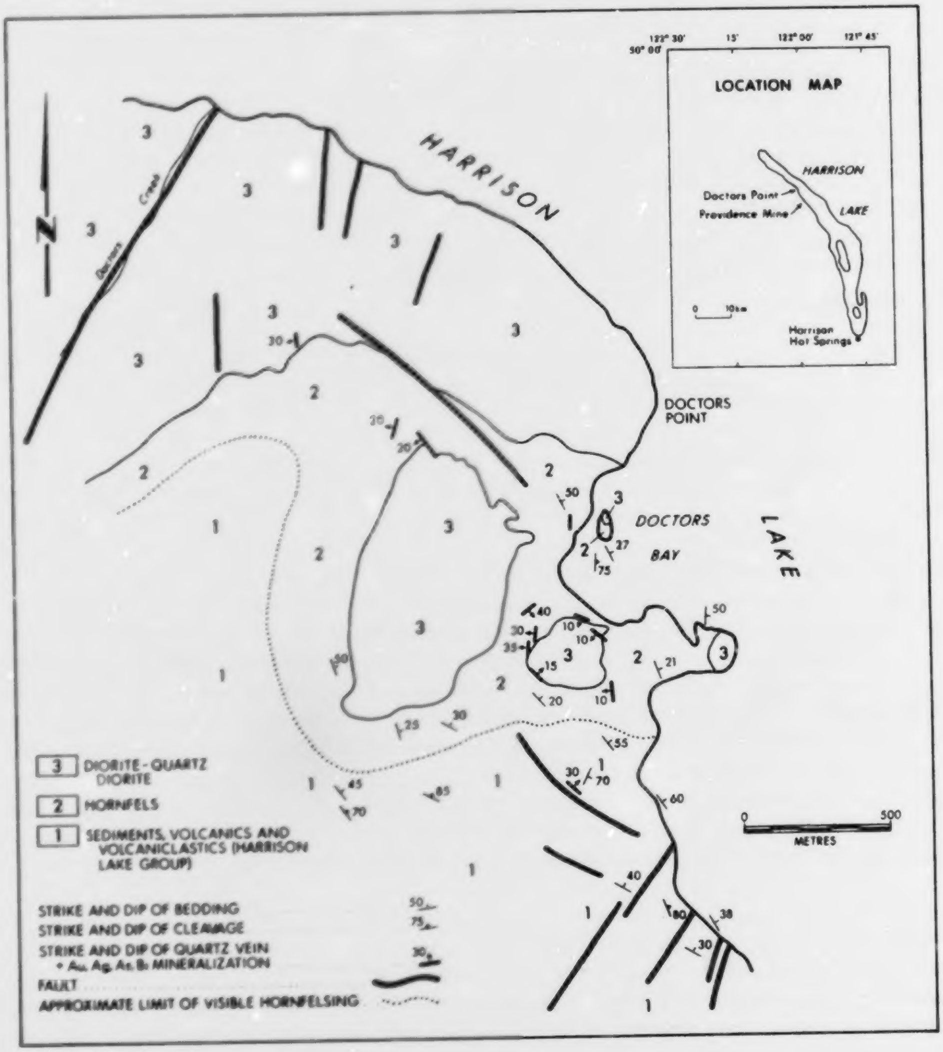
LOCATION MAP
122° 30'
15'
122° 00'
121° 45'
50° 00'
HARRISON LAKE
Doctors Point
Providence Mine
0 10km
Harrison Hot Springs
N
HARRISON
LAKE
DOCTORS POINT
DOCTORS BAY
Doctors Creek
0 500 METRES
3 DIORITE - QUARTZ DIORITE
2 HORNFELS
1 SEDIMENTS, VOLCANICS AND VOLCANICLASTICS (HARRISON LAKE GROUP)
STRIKE AND DIP OF BEDDING
STRIKE AND DIP OF CLEAVAGE
STRIKE AND DIP OF QUARTZ VEIN + Au, Ag, As, Bi MINERALIZATION
FAULT
APPROXIMATE LIMIT OF VISIBLE HORNFELSING

Figure 13. Geology of the Doctors Point area, Harrison Lake.

The Harrison Lake fracture system is associated with regional hot spring activity; this includes two hot springs along the Lillooet River valley, northwest of the lake, as well as one situated at Harrison Hot Springs on the southeastern extremity of the lake. The gold mineralization along the system is hosted in rocks of various ages and lithologies. The Fire Lake gold camp, situated approximately 20 kilometres northwest of Harrison Lake, includes six mineralized occurrences, all of which are found in quartz-rich veins that cut the Fire Lake Group. Five of these veins are hosted in greenstones and carry chalcopyrite and native gold. These quartz veins are not continuous but form lenses and gash fillings. The sixth mineral occurrence in the camp, the Dandy (Mineral Inventory 92G/NE-10), is hosted in brecciated sedimentary rocks and carries lead-zinc mineralization in a quartz-calcite vein.

At the RN mine (Geo), situated close to Harrison Hot Springs, the gold is hosted in sulphide-bearing quartz veins that cut both highly deformed metasedimentary rocks of the Chilliwack Group and intrusive diorite plutons.

The Providence mine, situated 5 kilometres southeast of Doctors Point, represents a fracture-filled vein deposit hosted in andesitic rocks of the Harrison Lake Group. The rocks in the Doctors Point area, where Rhyolite Resources Inc.'s mineralization was discovered, were originally assigned to the Fire Lake Group (Roddick, 1965) and the Mysterious Creek Formation (Monger, 1970). However, the prevalence of acidic to intermediate volcanic rocks in the area suggests they probably belong to the Harrison Lake Group. In the Providence mine vicinity, andesites and andesitic breccias predominate, but northward toward Doctors Point they become less abundant and are replaced by volcanic rocks of more acidic composition, together with coarse volcanic breccias, tuffs, and a variety of sedimentary rocks. At Doctors Point this supracustral assemblage is intruded by several diorite-quartz diorite plutons which are surrounded by wide and prominent thermal metamoprhic aureoles. The gold-bearing veins at Doctors Point exhibit a pronounced spatial relationship to the diorite pluton margins, but current geological data suggest the intrusions were not necessarily genetically related to the gold mineralization.

## DOCTORS POINT AREA

### INTRODUCTION

In the late 1970's, Mr. G. Nagy discovered gold-silver mineralization at Doctors Point, on the southwest shore of Harrison Lake, approximately 45 kilometres north-northeast of Harrison Hot Springs (Fig. 13). In 1981 Rhyolite Resources Inc. purchased the Nagy claims and subsequently conducted an exploration program involving geological mapping, soil sampling, trenching, and drilling. During August and September 1981, Rhyolite Resources Inc. put down 13 NQ drill holes totalling 890 metres. This program intersected gold-silver-bismuth mineralization in sulphide-bearing quartz veins; the best intersections were in holes 81R-8 and 81R-11 which respectively intersected 3.2 metres of 7.1 grams gold per tonne (0.21 ounce gold per ton) and 3.9 metres of 4.2 grams gold per tonne (0.125 ounce gold per ton). In July 1983 Rhyolite Resources Inc. announced they had completed 60 diamond-drill holes totalling 4 570 metres and had drill indicated and probable mineralized reserves of 450 000 tonnes grading 3.1 grams gold per tonne (0.1 ounce gold per ton) and 31 grams silver per tonne (1 ounce silver per ton).

### GEOLOGY

The simplified geology of the area is shown on Figure 13. The southern part is underlain by a variety of generally moderately dipping volcanic, volcaniclastic, and sedimentary rocks that probably belong to the Middle Jurassic Harrison Lake Group. To the north these supracrustals are intruded by five diorite-quartz diorite bodies that vary in size from only 25 metres in diameter to over 1 kilometre across. The volcanic rocks are fine to medium grained, are generally highly altered, and range from andesite to dacite in composition. Both porphyritic and non-porphyritic varieties are seen, and abundant disseminated pyrite is a widespread feature; the dacitic varieties are commonly devitrified and silicic. Most of the volcanic rocks are massive; flow banding is rarely seen.

The sedimentary rocks range from massive, black argillites, some of which contain rounded concretionary structures, through to finely bedded siltstones that in places display excellent graded bedding. Most of the sedimentary rocks indicate deposition in a low-energy environment but some siltstones contain argillitic rip-up clasts and others show signs of soft sediment deformation and chaotic slumping. The volcaniclastic rocks vary from finely bedded, often siliceous tuffs through to massive, chaotic volcanic breccias having angular to subangular clasts exceeding 0.3 metre in diameter. Most breccias are oligomictic, but some of the coarser varieties contain clasts of both dacitic and andesitic volcanic rocks, as well as fragments of bedded sedimentary material and broken quartz and felspar crystals. The more mafic breccias are marked by rounded clots of calcite rimmed by epidote. In places the bedded tuffs and breccias are interlayered with volcanic flows that also sporadically contain angular, lithic clasts. Consequently, it is often difficult to distinguish between these tuffaceous lavas and the volcaniclastic rocks, particularly where devitrification is widespread.

The plutons intruding the supracrustals (Fig. 13) range from diorite to quartz diorite in composition. When fresh they form grey-coloured, generally massive, and coarse-grained rocks. Biotite is the most widespread mafic mineral but hornblende is sporadically developed and can exceed 20 per cent by volume in parts. These rocks contain up to 10 per cent disseminated pyrite in places, but this sulphide does not contain gold.

Five individual plutons are seen. They range in size from the small body underlying the northern portion of the island in Doctors Bay through to the incompletely mapped large mass situated between Doctors Creek and Doctors Point (Fig. 13). The three remaining bodies form rounded to oval-shaped masses whose contacts with the country rocks are highly irregular in parts. Rounded, mafic zenoliths are seen in the largest pluton near Doctors Creek (Fig. 13) but are rare in the other four bodies. The largest pluton is also notable for its higher quartz content. The diorites are generally massive textured but the small body underlying the western extremity of the peninsula, south of Doctors Bay (Fig. 13), exhibits vertically inclined flow layering. This consists of subtle, diffuse concentrations of light and dark minerals with no signs of any sharp boundaries between individual layers which are mostly very regular and generally 1 to 2 centimetres wide. The plutons are surrounded by a 100 to 250-metre-wide hornfelsic zone marked by intense recrystallization of the country rock; in places identification of the original rock type is impossible. Close to the pluton margins the hornfels contains fine biotite and magnetite and is characterized by weak silicification with some disseminated fine-grained pyrite and pyrrhotite. The pyrite-pyrrhotite can exceed 15 per cent by volume immediately adjacent to the plutons but these intrusion-related sulphides do not carry gold. Two exposures of hornfelsic rocks containing coarse garnet crystals were also noted.

## GEOLOGICAL HISTORY OF THE DOCTORS POINT AREA

Middle Jurassic sedimentation and volcanism were followed by a period of uplift and folding which resulted in the consistent easterly dip of the bedding and the imposition of a subvertically inclined fracture and slaty cleavage. Bedding-cleavage intersections indicate that the entire area occupies the eastern limb of a major, northwest-trending anticline. There is no evidence of structural repetition in the sequence, and the graded bedding shows tectonic inversion did not occur. The temporal relationship between the diorite plutonism and the folding is unknown; however, no fracture cleavage is seen in the diorites. The plutons, subsequent to their intrusion were cut by narrow, mafic dykes. This event was followed by easterly directed thrust movements along thin, gently dipping thrust planes. Overall movement across individual thrust surfaces, however, was very small. Subsequently, gold-silver-bearing quartz-sulphide veins were injected along some thrust planes. This was followed by two sets of subvertically inclined faulting that trend northeast and southeast respectively. Slickensiding indicates the southeast-striking fault set suffered both vertical and subhorizontal movements.

## MINERALIZATION

The gold-silver mineralization at Doctors Point is hosted in long, narrow, generally gently dipping (10 to 30 degrees) quartz-sulphide veins that cut both the diorites and the adjacent hornfelsic rocks. On surface these veins vary from a few centimetres to 0.75 metre wide, but drilling has reportedly intersected veins over 2 metres in width. The veins include both clear and white vuggy quartz, the vug cavities being lined with small quartz crystals. Pyrite and arsenopyrite are the commonest sulphides; in part the veins comprise coarse, massive sulphide material in which quartz is subordinate. Surface leaching results in abundant boxwork textures in the quartz veins, and many mineralized outcrops are coated wtih green scorodite ($FeAsO_4 \cdot H_2O$), an alteration product of the arsenopyrite. In some instances the veins contain small amounts of chalcopyrite, while rare examples of molybdenum and galena are also reported. Analyses (Ray, 1983; Table 1) show that the gold-silver mineralization at Doctors Point is generally associated with anomalous amounts of bismuth, antimony, mercury, copper, and lead, and occasionally associated with anomalous values of zinc and tungsten.

### TABLE 1
### TRACE ELEMENT ANALYTICAL RESULTS, DOCTORS POINT, HARRISON LAKE*

| | 27852[1] | 27853[2] | 27854[3] | 27856[4] |
|---|---|---|---|---|
| Cu | 51 | 345 | 680 | 0.36% |
| Pb | 207 | 18 | 40 | 48 |
| Zn | 13 | 72 | 23 | 44 |
| Co | <2 | 146 | 2 | 5 |
| Mo | 8 | 2 | <2 | 7 |
| Hg (ppb) | 38 | <15 | 290 | 710 |
| Sb | 206 | <10 | 250 | 580 |
| As | 6.8% | <25 | 0.6% | 5.7 % |
| Ba | 240 | 400 | 770 | 370 |
| Bi | 4 | <2 | 17 | 55 |

All values in ppm except where recorded in per cent; Hg in ppb.

[1-4] Grab samples of sulphide-rich quartz veins on the Rhyolite Resources Inc.'s property, Doctors Point, Harrison Lake. Analysis by AA (Hg by cold vapour AA).

*For Au-Ag analyses on mineralized grab samples from the Doctors Point area see Ray (1983), Tables 1 and 2.

To date 13 mineralized veins are outlined on surface and the majority of these are located within 100 metres of the diorite-hornfels contact (Fig. 15). Surface veins are traceable over a 30-metre distance, but drilling indicates some exceed 200 metres in length. One surface vein is traceable from the diorite into the adjacent hornfels without any apparent dislocation or change in either mineralogy, vein dimension, or gold content.

The mineralized veins are usually bounded by a 'bleached zone' in which the nature and texture of the original rock type is unrecognizable. These bleached zones comprise a very fine mixture of quartz, sericite, and kaolin, with some disseminated pyrite; in places it carries trace amounts of gold. The bleached zone varies from a few centimetres to 3 metres in width; generally the wider zones are associated with the thicker veins, and commonly the hangingwalls contain the widest zones of alteration. The bleached alteration passes gradually out to a wider 'rotted zone' which is characterized by its friable, weathered, and rusty appearance. In this zone the feldspars are extensively kaolinized, but the textures of the original rocks are clearly visible. This alteration zone can exceed a total of 8 metres in width and generally carries weakly disseminated pyrite but no gold.

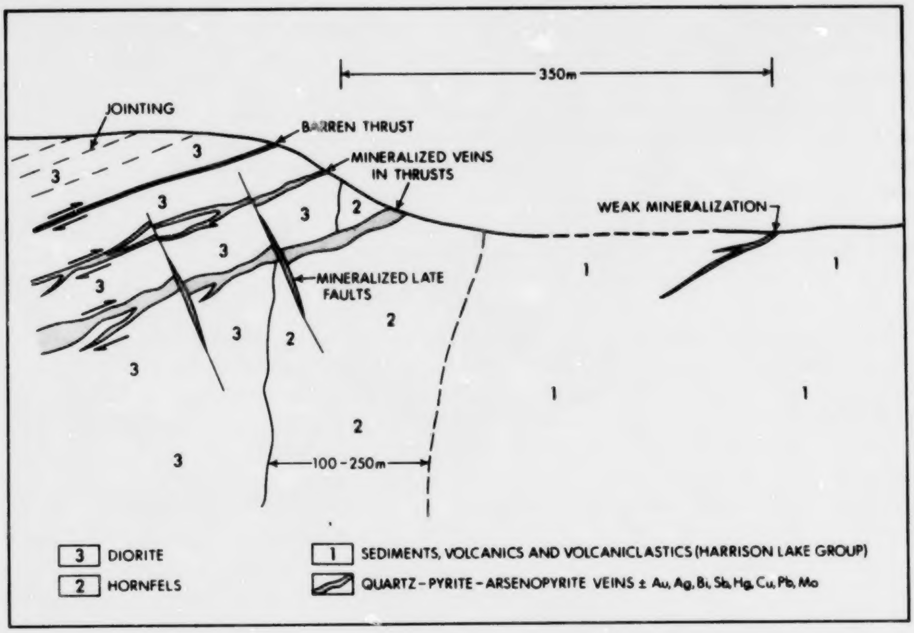
350m
JOINTING
BARREN THRUST
MINERALIZED VEINS IN THRUSTS
WEAK MINERALIZATION
MINERALIZED LATE FAULTS
100 - 250m
3
2
1
3 DIORITE
2 HORNFELS
1 SEDIMENTS, VOLCANICS AND VOLCANICLASTICS (HARRISON LAKE GROUP)
QUARTZ - PYRITE - ARSENOPYRITE VEINS ± Au, Ag, Bi, Sb, Hg, Cu, Pb, Mo

Figure 14. Schematic section showing mineralized quartz veins, Doctors Point, Harrison Lake.

The mineralized veins appear to follow, and be controlled, by a series of pre-existing, gently inclined thrust plane that cut both the diorites and the hornfelses. Most of these thrusts are unmineralized and in places they form a series of narrow, subparallel shear planes placed from 5 to 20 metres apart (Fig. 14). The unmineralized thrusts are marked by slickensiding and are rarely more than 3 centimetres wide; at one locality a subparallel set of gently dipping thrusts cutting the diorite contains grey, biotite-bearing granodiorite sills up to 0.3 metre wide. Most movement along the thrusts appears to predate the quartz-sulphide veins. However, the amount of movement across individual thrust planes appears to be small and one basic dyke that intrudes the diorites is offset only 7 to 10 metres across a mineralized vein. The displacement and slickensiding suggest the thrusting involved overall easterly directed movements.

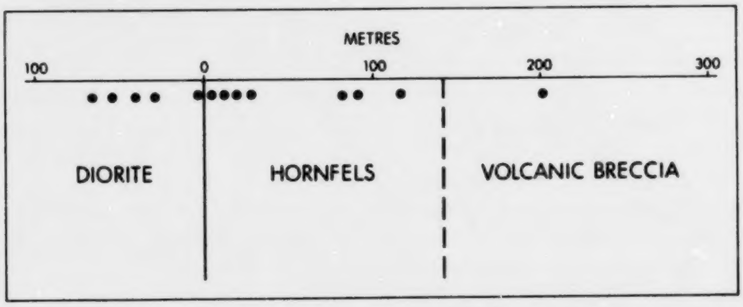

Figure 15. Relationship between mineralized veins (circles) and the diorite-hornfels contact, Doctors Point, Harrison Lake.

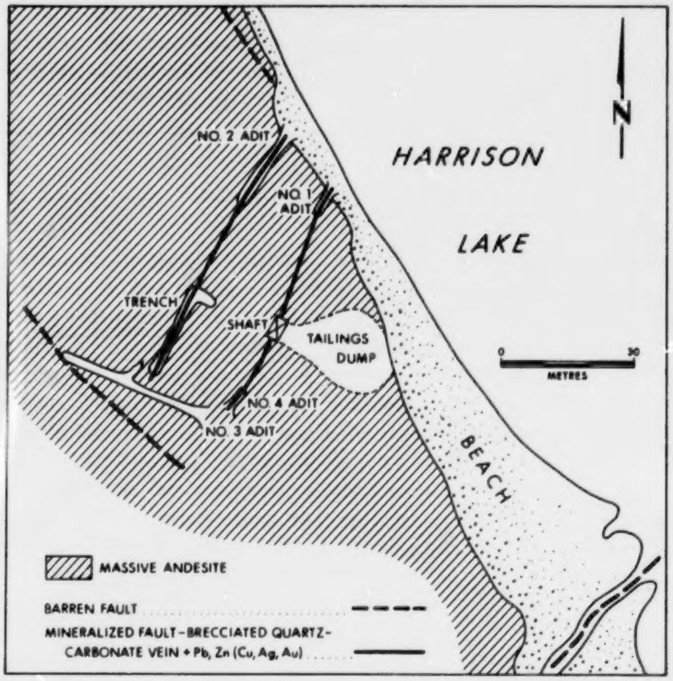

Figure 16. Geology and plan of the Providence mine workings, Harrison Lake.

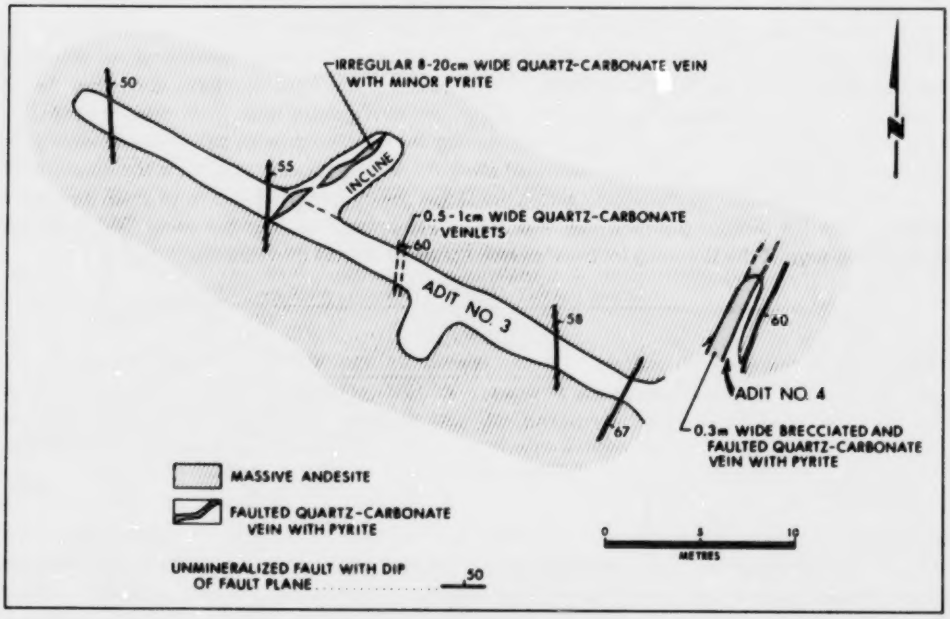
IRREGULAR 8-20cm WIDE QUARTZ-CARBONATE VEIN WITH MINOR PYRITE
50
55
INCLINE
0.5 - 1cm WIDE QUARTZ-CARBONATE VEINLETS
60
ADIT NO. 3
58
67
60
ADIT NO. 4
0.3m WIDE BRECCIATED AND FAULTED QUARTZ-CARBONATE VEIN WITH PYRITE
N
MASSIVE ANDESITE
FAULTED QUARTZ-CARBONATE VEIN WITH PYRITE
UNMINERALIZED FAULT WITH DIP OF FAULT PLANE
50
0
5
10
METRES

Figure 17. Geology of the Nos. 3 and 4 adits, Providence mine, Harrison Lake.

Drilling reveals that some mineralized veins bifurcate and rejoin one another in a complex manner, similar to that shown on Figure 14. Some late, subvertical normal fractures crosscut and cause minor displacement of the main veins. These later faults can also carry 1 to 3-centimetre-wide gold-bearing quartz-sulphide veins suggesting that some late remobilization occurred.

A petrographic and scanning electron microscope (SEM) study on the Doctors Point mineralization was completed by Littlejohn (1983). He noted that the native gold is associated mainly with the pyrite and only to a lesser extent with the arsenopyrite. The gold occurs as small inclusions, mostly less than 0.01 millimetre in diameter and is generally concentrated close to the edges of the sulphide crystals. Some pyrite and arsenopyrite crystals contain abundant, minute vesicles, which Littlejohn (1983) interprets to result from boiling. The numerous microfractures cutting the sulphides are filled with calcite, together with small amounts of gel pyrite, clay, and various silver-bismuth minerals, the most abundant of which are native bismuth and lead-bismuth sulphosalts. Argentite, associated with the bismuth minerals, is also present; some native bismuth contains minute specks of chalcopyrite. Traces of galena are intergrown with and rim the arsenopyrite.

Littlejohn (1983) concludes that the veins experienced two distinct episodes of precious metal mineralization. The first involved the introduction of gold with the sulphides and quartz, followed by a period of microbrecciation. The second resulted in injection of the silver-bismuth minerals into the microfractures. A period of calcite injection postdates the early quartz-sulphide-gold episode, but its precise relationship to the later silver-bismuth phase is unknown.

## PROVIDENCE MINE

### INTRODUCTION

Providence mine (Mineral Inventory 92H/NW-30) is situated close to the shore of Harrison Lake, on the north side of Davidson Creek, approximately 5 kilometres southeast of Doctors Point (Fig. 13). It was worked at the turn of the century and is covered by Crown grants (Lots 1737 and 1738). To date, no published description of either the mine workings, the geology, or the mineralization is available. The Annual Report of the Minister of Mines for 1897 described the property as containing 'three distinct lodes', the middle one being vertical and the other two converging toward the middle lode with depth. A 45-metre shaft was sunk over the middle lode and over 75 metres of tunnelling completed. Approximately 180 tonnes of ore was stockpiled and in 1896 three car loads of this material were shipped to the smelter; these averaged $27 per ton in gold and silver. However, individual assays varied from $1 to $2,000 per ton. The ore was described as containing about 40 per cent free gold, making it partially free milling.

### GEOLOGY AND MINERALIZATION

The regional geology around the Providence mine consists primarily of massive, dark green andesites, with lesser amounts of andesitic volcanic breccia. Adjacent to the mine area is a major, north-northeast-trending fault which passes along Davidson Creek (Fig. 16). The mineralization at the mine is controlled by several fractures which are either subparallel to, or represent splays from, the Davidson Creek fault. The geology and location of the adits and shaft, as determined by chain and compass survey, are shown on Fig. 16. Despite early descriptions of 'three lodes' on the property, only two mineralized veins were found during the present survey. The third vein is probably obsured by the tailings dump lying adjacent to the shaft.

Four adits were seen on the property. Two of these were driven in from the lake shore and follow the veins for short distances (Fig. 16). A short, 4-metre-long adit was also driven along the southern end of the eastern vein, together with a 34-metre adit which was driven from close by in a westerly direction (Fig. 16).

The latter adit attempted to intersect a southern extension of the western vein; however this vein must rapidly die out because it is poorly developed in the adit and contains only minor pyrite with no gold (Fig. 17). On surface this western vein was extensively and deeply trenched, while a shaft was driven down the central portion of the eastern vein (Fig. 16).

The veins are steeply dipping and have a maximum width of approximately 0.7 metre; they largely comprise a complex quartz-carbonate breccia that has sharp, often fractured contacts with the surrounding andesites. However, the wallrocks up to 3 metres from the veins carry irregular, subparallel veinlets of quartz and calcite, while the andesites immediately adjacent to the main veins contain disseminated pyrite. Sulphides are sporadically developed in the veins; in the No. 3 and No. 4 adits (Fig. 16) only weak pyrite is seen, while the trench overlying the western vein carries pyrite with weak chalcopyrite and rare bornite. On the tailings dump, however, numerous large specimens containing pyrite, galena, sphalerite, and lesser amounts of chalcopyrite are seen. In hand specimen the brecciated and mineralized vein material consists of angular to rounded clasts of rhythmically layered, crystalline and vuggy quartz up to 8 centimetres in diameter, embedded in a carbonate matrix. These quartz fragments tend to be matrix supported and do not appear to carry any sulphides. The carbonate cement is often rhythmically banded and associated with colliform layered, dark-coloured sphalerite, together with fine galena, chalcopyrite, and pyrite. In parts the carbonate material is also extensively brecciated and recemented, indicating the vein has suffered repeated fault movements. Trace element analyses on samples collected from the tailings dump are shown in Table 2. These show the lead-zinc-copper mineralization is associated with highly anomalous amounts of antimony, silver, and mercury; the latter reaching concentrations of up to 17 ppm (Table 2). The gold content, however, is surprisingly low (Table 2), which seemingly contradicts the early reports of high gold values in these veins (*Minister of Mines, B.C.*, Ann. Rept., 1897). However, the samples assayed in Table 2 were selected from the galena-sphalerite-chalcopyrite-bearing carbonate matrix, and none of the quartz breccia clasts were assayed. Thus, the gold in these veins is probably confined to the quartz clasts and is absent from the sulphide-bearing carbonate matrix.

**TABLE 2**
**TRACE ELEMENT ANALYTICAL RESULTS, PROVIDENCE MINE, HARRISON LAKE**

| | 28084[1] | 28085[2] | 28086[3] | 28087[4] |
|---|---|---|---|---|
| Au | 0.7 | <0.3 | <0.3 | 0.7 |
| Ag | 30 | <10 | 86 | 23 |
| Cu | 0.1 % | 115 | 0.55% | 160 |
| Pb | 0.36% | 255 | 0.7 % | 590 |
| Zn | 2.04% | 910 | 2.6 % | 0.37% |
| Co | 6 | 16 | 5 | 7 |
| Mo | <3 | 3 | <3 | 4 |
| Ni | 6 | 16 | 10 | 12 |
| Hg | 17 | 2 | 13 | 9 |
| Sb | 38 | 23 | 43 | 95 |
| Bi | 15 | <5 | 7 | 7 |

All values (including Hg) in ppm except where recorded in per cent.

[1-4] Grab samples of galena-sphalerite-chalcopyrite-bearing material from the tailings dump at Providence mine, Harrison Lake.

Au-Ag by fire assay; other elements by AA (Hg by cold vapour AA).

The complex brecciated textures in the veins suggest that the following sequence of deformation and mineralization occurred:

(1) Early northeast-trending, brittle faulting in the andesites produced subvertical, open fractures.

(2) Deposition of banded, crustiform, vuggy, possibly epithermal quartz, which probably carried the gold, mercury, bismuth, and antimony.

(3) A second period of faulting causing brecciation of the quartz vein.

(4) The introduction of the carbonate matrix, together with the lead, zinc, silver, and copper mineralization.

(5) A third period of faulting causing rebrecciation of the quartz and fracturing of the carbonate matrix.

This overall pattern of an early generation of quartz and gold, followed by the carbonate and silver, is similar to the sequence of mineralization in the Doctors Point area (Littlejohn, 1983). This, together with the enrichment of antimony and mercury, could indicate that mineralization in both areas is genetically and temporally related. The complex history also suggests that mineralization may have occurred over a relatively long time interval.

## RN MINE (GEO) (Mineral Inventory 92H/SW-92)

### INTRODUCTION

A very brief visit was made to the disused RN gold mine, situated approximately 4 kilometres northeast of Harrison Hot Springs. The property is being re-evaluated by Abo Oil Corporation who recently reported (Huber, 1983) that a 1 100-tonne test bulk sample averaged 45 grams gold per tonne (1.32 ounces gold per ton). The gold is hosted in quartz veins cutting a diorite-quartz-diorite pluton, close to its intrusive contact with hornfelsed, deformed slaty pelitic metasedimentary rocks. The latter are believed to belong to the Chilliwack Group. The visit involved both a surface examination of the old RN adit area and collection of mineralized samples from the nearby waste dump for assay (Table 3) and thin-section work.

**TABLE 3**
**TRACE ELEMENT ANALYTICAL RESULTS, RN MINE, HARRISON LAKE**

| | 28088[1] | 28089[2] |
|---|---|---|
| Au | 1.4 | 4.3 |
| Ag | <10 | <10 |
| Cu | 690 | 240 |
| Pb | 10 | 3 |
| Zn | 21 | 16 |
| Co | 19 | 31 |
| Mo | <3 | 6 |
| Ni | 15 | 8 |
| Sb | <3 | <3 |

All values in ppm.

[1, 2] Grab samples of sulphide-rich quartz vein material from waste dump, RN mine.

Au-Ag by fire assay, other elements by AA.

### GEOLOGY

The RN mine adit lies within a coarse, massive hornblende-biotite diorite close to its intrusive margin with Chilliwack Group metapelites. The diorite is cut by narrow, subhorizontal thrust planes which bifurcate and rejoin in places. These thrust planes vary from 8 to 25 centimetres wide and generally contain fault gouge and finely brecciated material. The gold is hosted in gently dipping to subhorizontally inclined white quartz veins. On surface near the adit portal, these have a maximum width of 0.3 metre. The veins have sharp contacts with the diorite; in some parts the margins are weakly sheared and exhibit slickensiding.

The veins contain both masses and disseminations of pyrrhotite with lesser amounts of pyrite. Pyrite locally forms coarse cubes. The pyrite distribution is patchy and appears to be a late mineral as it is associated with late crystalline quartz. Rare chalcopyrite is also present, and a single flake of molybdenum was noted in one sample. No gold was seen in any of the samples collected.

Fine sericite is also commonly associated with the veins, mostly being concentrated toward the margins and occasionally forming thin seams that separate the veins from the diorite. Some quartz crystals in the veins also include small blebs of calcite, while the diorite contains finely disseminated pyrrhotite and pyrite some considerable distance from the vein contacts. The analytical results (Table 3) indicate that the sulphide-rich, gold-bearing quartz veins contain weakly anomalous amounts of copper and molybdenum. However. in contrast to the mineralization at Providence mine and Doctors Point, there is no enrichment in either mercury or antimony.

## GENERAL CONCLUSIONS ON THE HARRISON LAKE AREA

(1) Gold mineralization along the Harrison Lake fracture system is hosted in rocks of various ages and lithologies, including basic volcanic rocks, plutonic diorites, and hornfelsed volcanic and sedimentary rocks.

(2) It is unknown whether the various occurrences are the result of a single, regionally distributed gold-mineralizing event, or whether they are of widely different ages. Age dating of both the host rocks and the sericite-bearing occurrences could resolve this question.

(3) All the gold occurrences and deposits represent vein-type mineralization. Two examples (Dandy and Providence mine) are hosted in quartz-carbonate veins, while the remainder are in quartz-rich veins.

(4) At both Doctors Point and the RN mine the veins were controlled by pre-existing, gently inclined thrust planes. Thus, thrusting may have played an important role in both the regional tectonic history and in locally controlling some of the gold mineralization. The remainder of the occurrences are found in steeply dipping, fracture-filled veins.

(5) Gold throughout the region is always associated with varying amounts of sulphides, of which pyrite and chalcopyrite are the most widespread. Abundant galena and sphalerite are found at the Dandy occurrence and Providence mine. Arsenopyrite is abundant at Doctors Point but is absent from the RN and Providence mines mineralization.

(6) Mercury, antimony, and bismuth are associated with the gold at Providence mine and Doctors Point. By contrast, no mercury and antimony are present at the RN mine. (Bismuth analyses on samples from the RN property are not yet available.)

(7) Both the Doctors Point and Providence mine mineralization involved an early generation of gold-quartz injection followed by a later phase of carbonate-silver-lead mineralization.

(8) The vuggy, rhythmically layered quartz at Providence mine, together with mercury and antimony enrichment, suggests it represents lower temperature, possibly epithermal-type mineralization. By contrast, the presence of abundant sericite at Doctors Point and the RN mine suggests the mineralization in these two areas represents higher temperature, possibly mesothermal-type veining.

(9) The mineralized veins at Doctors Point are spatially related to the intrusive margins of diorite plutons. However geological evidence suggests no genetic relationship exists because the plutonic intrusion and mineralization were separated by a considerable time interval.

(10) Reconnaissance mapping indicates the Doctors Point area lies close to a Middle Jurassic acid volcanic centre. Similar volcanic centres could exist elsewhere in the Harrison Lake Group and these would represent good targets for gold exploration.

(11) To date, no large tonnage, low-grade epithermal-type gold mineralization has been discovered along the Harrison Lake fracture system. This could reflect the lack of modern geological mapping and exploration in the area. The fracture system is associated with many highly favourable geological and geochemical factors that indicate it represents an excellent, highly accessible regional exploration target for both vein-type and Carlin or Cinola-type gold mineralization.

## ACKNOWLEDGMENTS

The authors wish to thank the management and staff of Rhyolite Resources Inc. for their active cooperation and assistance during this project, particularly the President, Mr. J. Stewart. Assistance in the field by P. Desjardins is gratefully acknowledged as are informative discussions with W. J. McMillan, A. Panteleyev, and P. Wilton.

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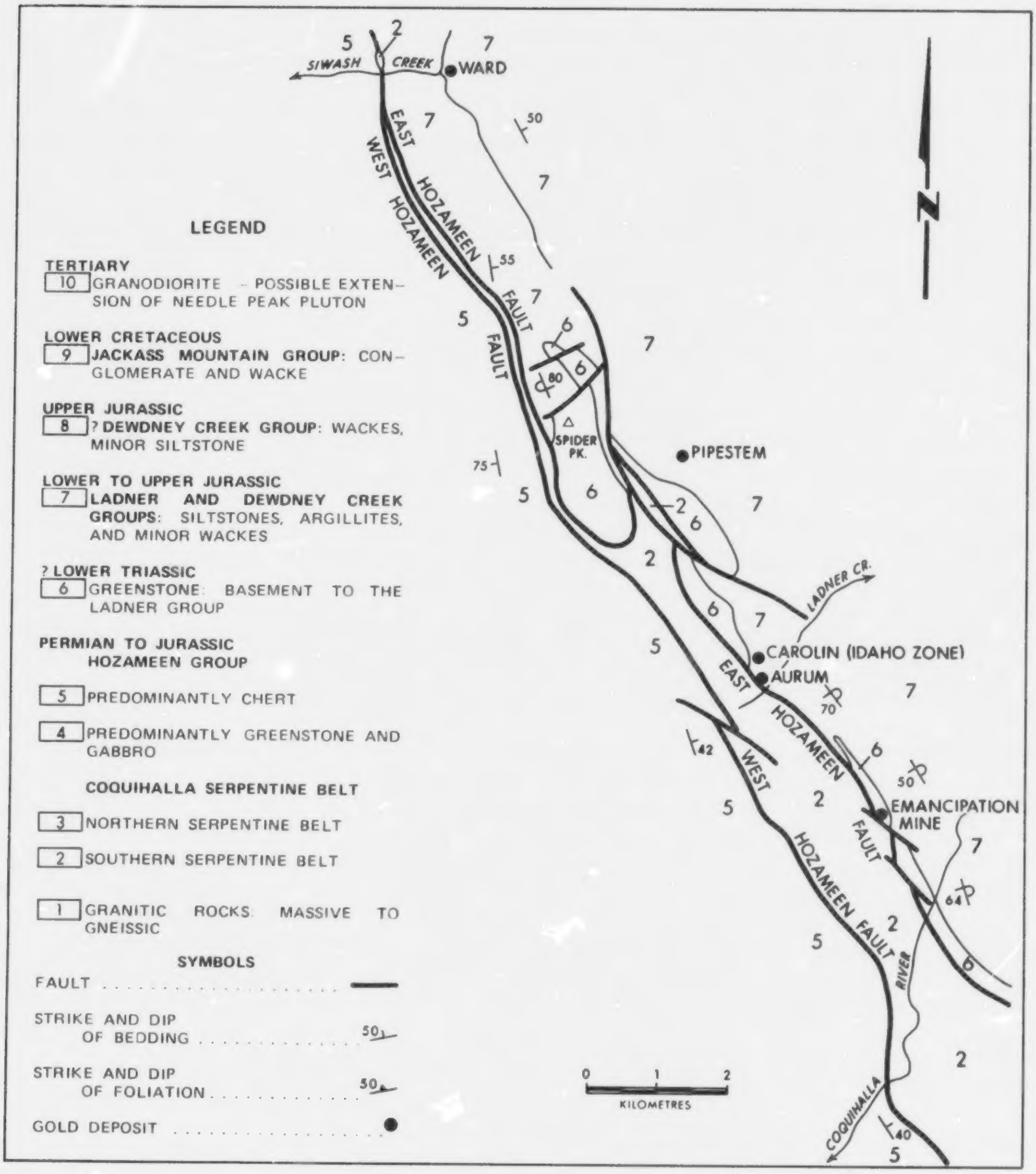
LEGEND
TERTIARY
10 GRANODIORITE – POSSIBLE EXTENSION OF NEEDLE PEAK PLUTON
LOWER CRETACEOUS
9 JACKASS MOUNTAIN GROUP: CONGLOMERATE AND WACKE
UPPER JURASSIC
8 ? DEWDNEY CREEK GROUP: WACKES, MINOR SILTSTONE
LOWER TO UPPER JURASSIC
7 LADNER AND DEWDNEY CREEK GROUPS: SILTSTONES, ARGILLITES, AND MINOR WACKES
? LOWER TRIASSIC
6 GREENSTONE: BASEMENT TO THE LADNER GROUP
PERMIAN TO JURASSIC HOZAMEEN GROUP
5 PREDOMINANTLY CHERT
4 PREDOMINANTLY GREENSTONE AND GABBRO
COQUIHALLA SERPENTINE BELT
3 NORTHERN SERPENTINE BELT
2 SOUTHERN SERPENTINE BELT
1 GRANITIC ROCKS: MASSIVE TO GNEISSIC
SYMBOLS
FAULT
STRIKE AND DIP OF BEDDING 50
STRIKE AND DIP OF FOLIATION 50
GOLD DEPOSIT ●
N
SIWASH CREEK
WARD
EAST HOZAMEEN FAULT
WEST HOZAMEEN FAULT
SPIDER PK.
PIPESTEM
LADNER CR.
CAROLIN (IDAHO ZONE)
AURUM
EMANCIPATION MINE
COQUIHALLA RIVER
0 1 2
KILOMETRES
50
55
80
75
70
42
50
64
40

Figure 18. Geology between Coquihalla River and Siwash Creek.

# COQUIHALLA GOLD BELT PROJECT
## (92H/11, 14)

By G. E. Ray

## INTRODUCTION

A third and final field season's mapping along the northern portion of the Coquihalla serpentine belt was completed using a two-man field crew. The work included the following:

(1) Regional geological mapping (scale 1:15 000) comprising an 85-square-kilometre, elongate strip stretching from the vicinity of Boston Bar southward to the Spider Peak area (Figs. 18, 19, and 20). Mapping was concentrated in areas adjacent to both the Hozameen fault system and the Coquihalla serpentine belt.

(2) Surface examination and sampling of the gold-bearing 'Monument' quartz vein (Mineral Inventory 92H/NW-54; Fig. 19).

(3) Collecting grab samples from any sulphide-rich or gossanous zones encountered during the mapping. These were assayed for base and precious metals.

(4) Collecting limestone samples from the Hozameen Group for microfossil age dating.

## REGIONAL GEOLOGY

The regional geology adjacent to the Hozameen fault system from Coquihalla River to Boston Bar is shown on Figures 18, 19, and 20. South of Carolin mine (Fig. 18) the Coquihalla serpentine belt forms an elongate, steeply dipping unit that exceeds 2 kilometres in outcrop width; the eastern and western margins of the belt are defined by two major fractures, the East and West Hozameen faults (Ray, 1983) that suffered recurrent vertical and transcurrent movement. The serpentine belt separates the Hozameen Group to the southwest from the Jurassic Ladner Group to the northeast (Fig. 18). The Hozameen Group comprises an ophiolitic sequence of cherts, pelites, and basaltic greenstones, while the Ladner Group consists largely of a succession of turbiditic wackes, siltstones, and slaty argillites. Northward from Carolin mine the belt gradually thins until in the vicinity of Siwash Creek (Fig. 19) the Hozameen and Ladner Groups are either in direct fault contact, or separated by narrow lenses of fault-bounded serpentinite that are generally less than 100 metres in width. North of Gilt Creek (Fig. 19) serpentinites associated with the Hozameen fault disappear entirely; from this vicinity northward to the confluence of the Fraser and Anderson Rivers (Fig. 20), the Hozameen and Ladner Groups are in direct fault contact. However, near Petch Creek (Fig. 20), where serpentinites are exposed on the Trans-Canada Highway, southward to an area approximately 2 kilometres northeast of Chapmans Bar, there is a prominent, continuous belt of serpentinite up to 500 metres in width. This belt marks the western, highly tectonized margin of the Hozameen Group and separates this oceanic, mostly suprascustal assemblage from granitic rocks lying immediately to the west. Thus the Coquihalla serpentine belt, which was regarded formerly as a single, discontinuous elongate unit (Cairnes, 1929; Monger, 1970; Ray, 1983), is separable into dissimilar northern and southern belts. These two belts have contrasting structural and stratigraphic relationships; limited data suggest they also possess marked petrographic and geochemical differences. Consequently, the northern and southern serpentine belts are probably unrelated; their regional on-strike position is coincidentally caused by a set of younger,

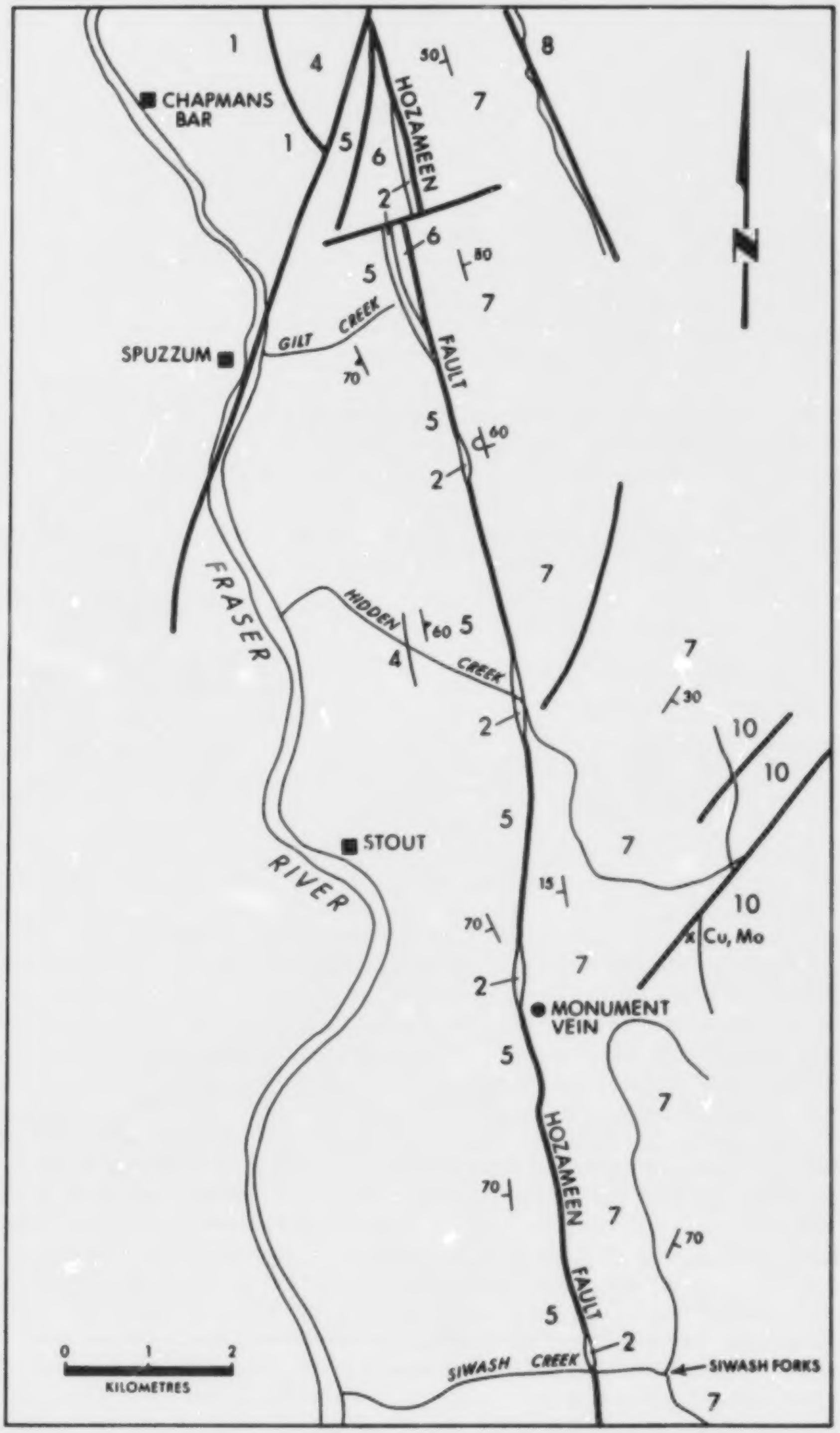

Figure 19. Geology between Siwash Creek and Gilt Creek.

oblique faults that pass from Spuzzum north-northeastward to the Anderson River (Figs. 19 and 20). South of Spuzzum this younger but major fault, which probably belongs to the Fraser fault system, continues along the Skeemis Creek valley; north of Gilt Creek it causes at least 5 to 6 kilometres of right lateral displacement on the older Hozameen fault.

A broad stratigraphic succession is recognized in the Ladner Group (Ray, 1982, 1983) comprising a heterogeneous lower unit of lithic wackes and conglomerates passing upward into finer grained, more regularly bedded siltstones and slates. The lower clastic unit is economically important because it hosts many of the gold occurrences in the Coquihalla gold belt, including the Idaho zone orebody of Carolin Mines Ltd. The lower unit is best developed in the vicinity of this mine, where it exceeds 200 metres in thickness and unconformably overlies an older pillowed volcanic greenstone sequence of possible Early Triassic age (Ray, 1983). Further north and south, however, the fault cuts progressively to higher stratigraphic levels in the Ladner Group. Consequently, north of Spider Peak the Hozameen fault cuts mostly slates and siltstones in the higher part of the Ladner Group succession, and the lower coarsely clastic unit is generally absent. The basement greenstones underlying the Ladner Group generally lie south of Spider Peak (Fig. 18). North of Gilt Creek (Fig. 19), however, there is another 2-kilometre-long unit of presumed basement greenstone exposed which is bounded by faults and serpentinites; it could represent a tectonic slice of basement greenstone offset from similar rocks in the Spider Peak area by transcurrent movement along the Hozameen fault. If this interpretation is correct, it indicates that at least 18 kilometres of right lateral transcurrent displacement took place along this portion of the Hozameen fault system.

Approximately 5 kilometres east of Stout (Fig. 19) the folded, often gently dipping siltstones of the Ladner and Dewdney Creek Groups are intruded by a large body of massive granodiorite; it covers at least 3 square kilometres but its full dimensions are unknown. This granodiorite probably represents a northern, previously unmapped extension of the Needle Peak pluton; the Needle Peak pluton has been dated by K/Ar methods at 39 Ma (Wanless, *et al.*, 1967). The contact of the granodiorite intrusion is marked by a metamorphic aureole up to several hundred metres wide in the Ladner Group, together with swarms of both porphyritic and even-grained felsic sills and dykes. At least three types of felsic dykes comprise the swarms; these are:

(1) feldspar porphyries with coarse euhedral feldspar crystals up to 3 centimetres across,
(2) quartz porphyries with rounded quartz crystals up to 4 millimetres in diameter, and
(3) even-grained, siliceous dacitic sills and dykes containing small amounts of biotite and pyrite.

Most sills and dykes are less than 30 metres wide but the feldspar porphyries are extremely widespread within the Ladner Group throughout the district; in places this suite is associated with weak gold mineralization as, for example, at the Spuz occurrences (Mineral Inventory 92H/NW-55). These felsic sills predate the main movement on the Hozameen fault, since they are confined to the Ladner Group and absent from both the serpentine belt and the Hozameen Group. Since geological mapping indicates that these sills are related to the Needle Creek pluton, it suggests that the major movements along the Hozameen fault took place less than 39 Ma ago.

The Hozameen Group between Gilt Creek and Spider Peak (Figs. 18 and 19) comprise a highly deformed assemblage of cherts, argillites, and altered greenstones in which no stratigraphic succession is recognized. The assemblage is cut by several suites of intrusive rocks of felsic to intermediate composition that includes some distinctive quartz porphyries. These intrusive rocks do not occur in the adjacent serpentinites or Ladner Group, which indicates that they predate the main transcurrent movements along the Hozameen fault. Between Boston Bar and Gilt Creek (Figs. 19 and 20) a much wider section of the Hozameen Group has been mapped. The oblique right lateral faulting north of Gilt Creek has moved this northern segment of Hozameen Group rocks, together with its westerly bounding serpentinite belt and adjacent granitic rocks, some 5 to 6 kilometres to the north-northeast. The Hozameen Group assemblage in this northern segment, like that south of Gilt Creek, has been intensely deformed and the overall structure is still poorly

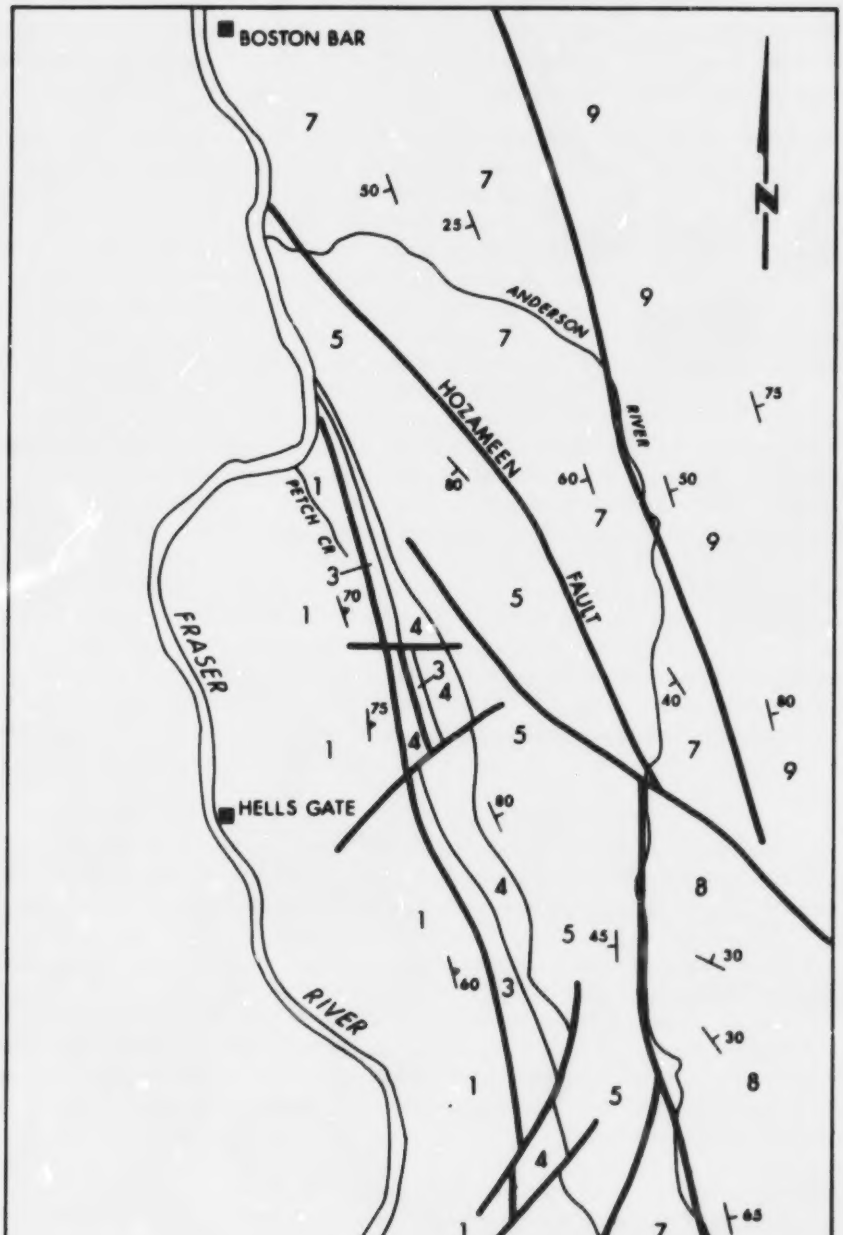

Figure 20. Geology of the Anderson River—Chapmans Bar area.

understood. Nevertheless, a broad stratigraphic succession is recognized in the northern segment, consisting of serpentinites at the base, overlain by a thick unit of greenstones, gabbros, and diorites, which passes stratigraphically upward into a thick sequence of cherts with minor greenstones and argillites. A mixed sequence of cherts, greenstones, altered volcanogenic sedimentary rocks, and small, grey limestone lenses may represent the highest portion of the Hozameen Group stratigraphy exposed in this area, although structural interpretation makes this uncertain. This succession provides supportive evidence that the Hozameen Group represents an ophiolite suite.

The northern serpentine belt represents the deepest recognized portion of the Hozameen Group succession and also generally marks the westernmost boundary of the group (Fig. 20). The belt is fault bounded and mostly dips between 40 to 70 degrees east. The serpentinites in the northern segment differ from those associated with the Hozameen fault further south; they commonly include slices of altered ultramafic material in which primary igneous textures are still recognizable. Locally the stratigraphically and structurally overlying greenstone unit also contains thin, discontinuous serpentinite slices. The sharp, easterly dipping tectonic contact between the serpentinites and the granitic rocks to the west is marked by faulting and shearing. In some places the granites immediately adjacent to the serpentinites show signs of mylonitization. The granitic rocks are texturally varied, ranging from massive, apparently undeformed pink to white granodiorite, to well-foliated rocks which includes both leucogranites and highly mafic material. Minor amounts of grey, moderately foliated granitic gneiss are also seen; the latter could represent thin, tectonic slices of Custer gneiss. The granitic rocks approximately 2 kilometres east-southeast of Hells Gate (Fig. 20) include a thin, elongate xenolith of grey marble more than 250 metres in length. The highly deformed marble contains sharply angular, matrix-supported clasts of pink leucogranite up to 20 centimetres in diameter; these clasts probably have a tectonic origin.

The intense faulting and the sporadic development of foliated and mylonitized granites indicate that the western margin of the Hozameen Group represents a major, previously unrecognized fault. This fracture apparently cuts granitic rocks in the Hells Gate-Yale area; these granites have been dated by K/Ar methods at approximately 40 Ma (Wanless, *et al.*, 1967) which sets an older time limit for this fault movement.

## ECONOMIC GEOLOGY

The area between Spider Peak and Gilt Creek (Figs. 18 and 19) has been actively prospected over the last 90 years and a number of gold occurrences have been located; these include the Roddick, Emigrant, Marvel, Majestic, Gold Coin, Gold Cord, Spuz, and Monument, as well as the Ward deposit which was briefly worked in 1905. Apart from the Spuz and Monument occurrences, no detailed geological descriptions are available; both the nature of the mineralization and precise locations are uncertain. The remains of an old stamp mill and several collapsed adits at Siwash Forks (Fig. 18) are believed to be the old Ward mine workings (Mineral Inventory 92H/NW-15); reportedly 4 kilograms of gold were produced in 1905 (Mineral Inventory File). The geology in this vicinity comprises Ladner Group slaty argillites with minor amounts of well-bedded siltstones; they are intruded by a large number of porphyritic and massive felsic sills. One short exploratory adit on the north side of Siwash Forks follows the edge of a sill; it seems likely that the gold in this vicinity was won from quartz veins cutting the felsic intrusions.

Another series of adits was reported on the Emigrant property (*Minister of Mines, B.C.*, Ann. Rept., 1917) on the south fork of Siwash Creek; these were not seen during the present work. The Majestic (Mineral Inventory 92H/NW-33) is situated in the upper part of Hidden Creek (Fig. 19) where a collapsed adit is reported. This area is underlain by Ladner Group slaty argillites and siltstones that are intruded by numerous felsic sills. The weak gold mineralization on this property is also probably found in quartz veins cutting these felsic intrusions.

The Monument gold occurrence (Mineral Inventory 92H/NW-54), situated 3 kilometres southeast of Stout (Fig. 19), is hosted in a steeply dipping 1 to 2.5-metre-wide quartz vein that has a strike length of approximately 350 metres (Cochrane and Littlejohn, 1978; Cardinal, 1982). The Monument vein is subparallel to, and 200 metres east of, the Hozameen fault; it is hosted in deformed slaty argillites of the Ladner Group. The white quartz vein contains minor amounts of fine pyrite with rare arsenopyrite and chalcopyrite; five grab samples collected by Cochrane and Littlejohn (1978) averaged 2.8 grams gold per tonne (0.084 ounce per ton) with one richer sample assaying 10.1 grams gold per tonne (0.297 ounce per ton). Cochrane and Littlejohn (1978) report that visible gold in the Monument vein occurs either as small rounded particles between 0.5 to 2 millimetres in diameter embedded within vuggy quartz or as small thin flakes coating shear surfaces at the quartz vein-argillite contact.

The Spuz occurrences (Mineral Inventory 92H/NW-55) comprise numerous minor gold showings that are associated with felsic sills and dykes which intrude the Ladner Group north and northwest of Siwash Forks. The very fine, erratic gold is hosted in narrow quartz and quartz-calcite veins that fill brittle fractures and boudin structures in the sills. These veins also carry sparse pyrite and rare arsenopyrite (Cochrane and Littlejohn, 1978; Cardinal, 1982), while the former authors also report the presence of rare scheelite mineralization.

The felsic sills associated with the granodiorite body 5 kilometres east of Stout (Fig. 19) are occasionally related to weak pyritization in the adjacent country rocks. However, more intense, pervasive sulphide alteration is seen in the thermally altered siltstones within 1 kilometre of the granodiorite margin, where dyke swarms of felsic intrusive rocks are common. The metasedimentary rocks contain disseminated pyrite with some weak silicification and iron carbonate alteration. This pyritization appears to be associated with the siliceous dacitic sills and not related to the more abundant feldspar porphyry intrusions. Grab samples of sulphide-rich material were assayed for base and precious metals without significant results. However, at one locality (620100E – 5498500N) less than 100 metres from the granodiorite margin (Fig. 19), the thermally altered, sulphide-rich siltstones are cut by 5 to 8-centimetre-wide vuggy quartz veins which are folded and sheared. These veins contain pyrite, chalcopyrite, and some coarse flakes of molybdenum, but no gold. This previously unreported copper-molybdenum occurrence suggests that the Needle Peak pluton and its thermal aureole could represent a viable exploration target for base metals and possibly gold.

## DISCUSSION

### REGIONAL CONTROLS OF MINERALIZATION IN THE COQUIHALLA GOLD BELT

The Coquihalla gold belt comprises the currently operating Carolin mine and four past producers (Emancipation, Aurum, Pipestem, and Ward), as well as 19 minor gold occurrences (*see* Table 3, Ray, 1983). These deposits and occurrences are extremely variable in their form, geochemistry, mineralogy, and host rock lithology; this makes it difficult to recognize common relationships and controls. For example, the producers are hosted in several different rock lithologies: Carolin and Pipestem in sedimentary wackes, Emancipation in volcanic greenstones, Aurum in talcose shears, and the Ward* in felsic sills. Their form varies widely from discrete quartz veins as seen at Emancipation mine, to more diffuse, possibly replacement-type orebodies as found at Carolin mine. The gold-bearing quartz veins at Emancipation mine and the Monument and Murphy occurrences are sulphide poor, whereas the mineralization at Carolin mine and the McMaster zone are rich in pyrite, pyrrhotite, and arsenopyrite.

The sparse available data suggest the gold mineralization along the belt exhibits some geochemical as well as mineralogical differences. No mercury enrichment is reliably reported from any occurrence or deposit but both the Carolin deposit (Ray, 1983) and the Monument vein (Cochrane and Littlejohn, 1978) are

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*No geological description of the Ward mine exists. The assumption that the mineralization was hosted in felsic sills is based on the geology in the Ward mine area.

associated with anomalous tungsten values. The identical mineralogy and geochemistry of the Carolin deposit and the McMaster zone suggest that the two are related and synchronous; they are distinctive in that the gold-sulphide mineralization is associated with abundant albite. No such sodium enrichment is reported elsewhere in the belt. The Aurum mineralization is unique because it is the only example where gold occurs within the East Hozameen fault; it is closely associated with the talcose, highly sheared serpentinite margin. It also appears to include a variety of sulphides, including millerite (Cairnes, 1929).

Despite these variations some generalizations are possible. In all cases the introduction of gold was accompanied by variable amounts of silica and at least four forms of orebody or occurrences are recognized; these are:

(1) Thin, highly irregular and generally discontinuous quartz veins; these host the majority of the minor gold occurrences including the Murphy and Spuz occurrences.

(2) More continuous, wider, and discrete quartz veins as seen at the Emancipation mine and the Monument occurrence.

(3) Irregular orebodies hosted in highly fractured, coarse clastic sedimentary rocks which are associated with silicification, network quartz veining, albitization, and abundant sulphides as present at the Carolin mine deposit and the McMaster zone. Recent underground mapping by Carolin mine geologists (Shearer and Niels, 1983) shows that the Idaho zone mineralization is concentrated in an antiformal hinge zone.

(4) Gold within talcose shears along the East Hozameen fault immediately adjacent to serpentinites and Ladner Group metasedimentary rocks. The Aurum mineralization is the only discovered example of this type.

When the deposits and occurrences in the belt are examined, some relationships between their host rock types, and their distance from both the East Hozameen fault and the greenstone-Ladner Group contact are discernible. Figure 21a shows the five gold producers together with 13 occurrences for which reliable data is available; it plots their host rock type and relative distance from the East Hozameen fault and serpentinite contact. This shows the gold is found only east of the East Hozameen fault and none is reported from within the serpentine belt. Moreover, the majority of occurrences are hosted in metasedimentary rocks, mostly belonging to the Ladner Group. While gold can be found up to 1 kilometre east of the serpentine belt, most occurrences and deposits are concentrated within 600 metres of the East Hozameen fault. Figure 21b clearly demonstrates moreover, that most gold production in the belt was derived from deposits less than 200 metres from the serpentinite margin and East Hozameen fault.

Figure 22a reveals the close spatial relationship that exists between the greenstone-Ladner Group contact and various deposits and occurrences for which reliable location data exist. This relationship is further demonstrated on Figure 22b which shows that over 95 per cent of the gold production from the belt has taken place within 150 metres of this lithological contact.

Thus, the main regional controls to mineralization in the Coquihalla gold belt are:

(1) The presence of competent rocks suitable for open space fracturing. Consequently the area between the Emancipation mine and Spider Peak, where the lower coarse clastic rocks of the Ladner Group are best developed, contains most of the sediment-hosted gold occurrences, as well as the Carolin mine deposit (Fig. 18).

(2) Close proximity to the volcanic greenstone-Ladner Group contact. In many places the unconformable contact, due to competency differences, is marked by shearing, brittle fracturing, and quartz veining.

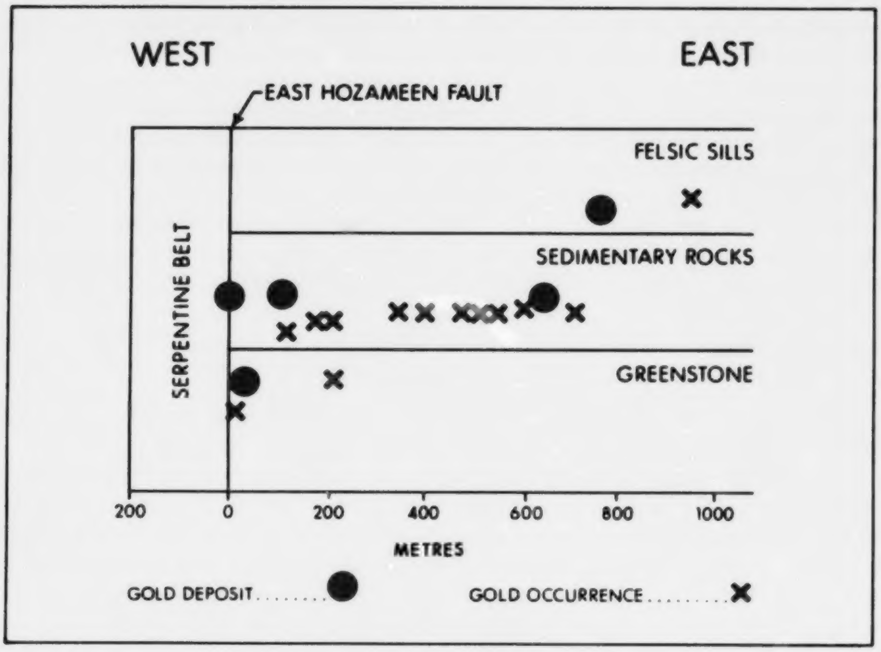

Figure 21a. Coquihalla Gold Belt – relationship between host rock lithologies and distance of mineralization from the East Hozameen fault.

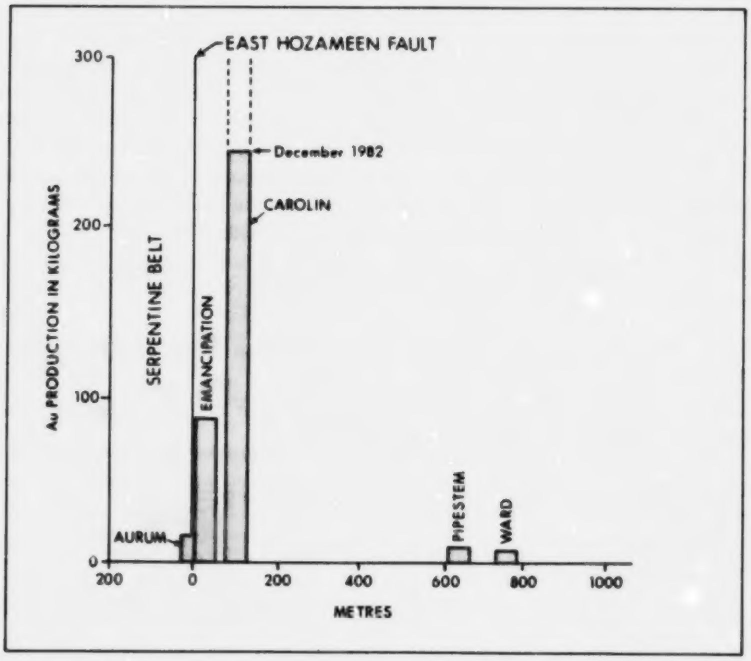

Figure 21b. Relationship between gold production from the Belt and distance from the Hozameen fault.

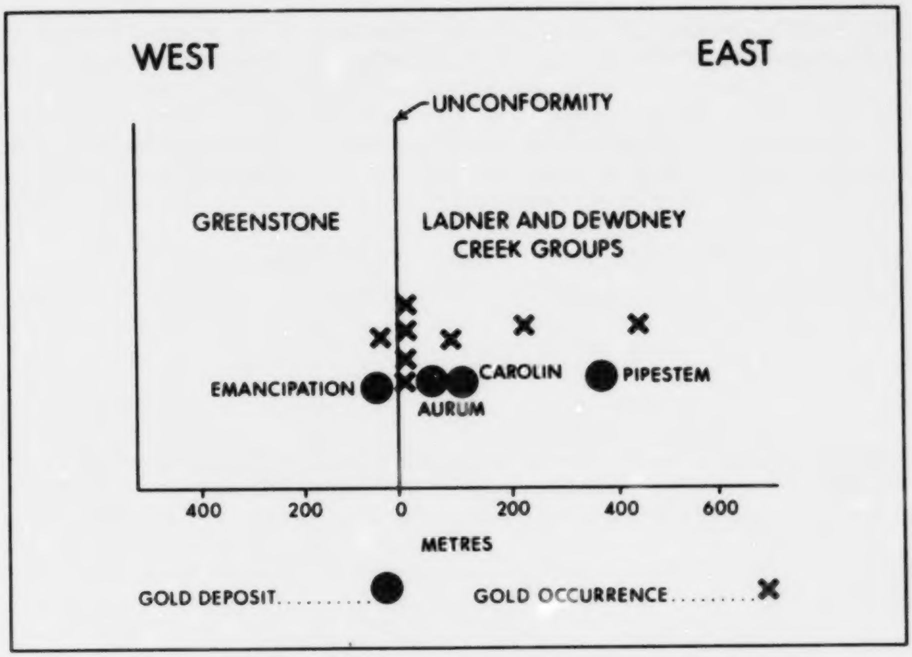

Figure 22a. Coquihalla Gold Belt — relationship between gold mineralization and the Ladner Group—greenstone contact.

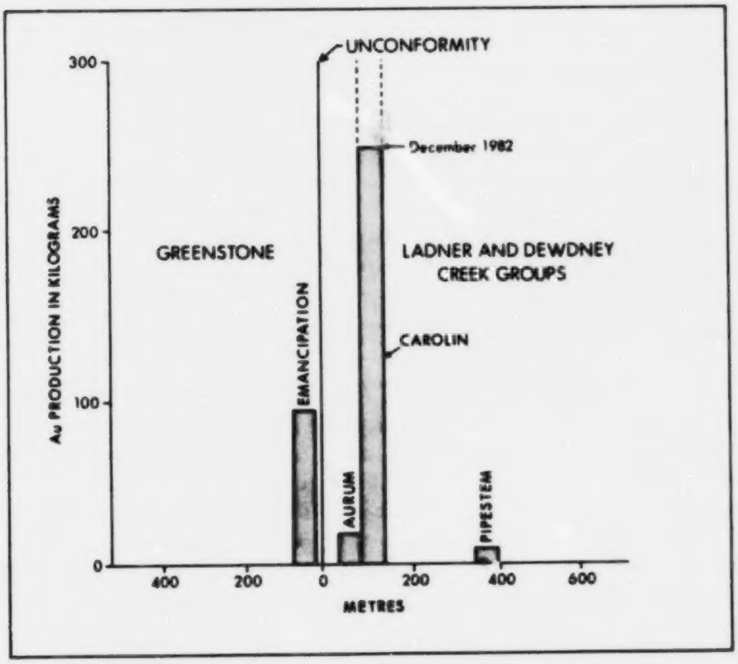

Figure 22b. Relationship between gold production and the Ladner Group—greenstone contact.

(3) Close proximity (less than 200 metres) to the East Hozameen fault and serpentinite margin. However, this fault does not represent a single fracture that suffered recurrent movements, but instead comprises several generations of oblique, intersecting faults as seen in the Emancipation mine vicinity (Fig. 18). This probably accounts for the variation in intensity of shearing and alteration along the fault system. In some parts the serpentinite contact is sharp and unaltered, whilst close to the Emancipation and Aurum deposits the fault is occupied by a wide unit of highly sheared talc. The gold mineralization may only show a spatial relationship to one particular generation of fracturing in the East Hozameen fault system, which would explain why certain areas adjacent to the fault, despite having favourable brittle host rocks, do not contain any gold occurrences.

## SUMMARY

(1) The Coquihalla serpentine belt, which was previously regarded as a single, related unit, is separable into distinctive northern and southern belts which have entirely different tectonic relationships and are probably unrelated to each other.

(2) The northern serpentine belt generally occupies the western, highly tectonized margin of the Hozameen Group; it separates these rocks from variable granitic rocks further west.

(3) The southern belt is associated with the Hozameen fault system and generally marks the eastern boundary of the Hozameen Group, separating these supracrustal rocks from the Ladner Group further east.

(4) Numerous gold occurrences and deposits are located adjacent to the southern serpentine belt, but the northern belt is not associated with any gold mineralization. This suggests that the two belts could have fundamental geochemical differences.

(5) The Hozameen Group contains a broad stratigraphy consisting of basal serpentinites (northern serpentinite belt) overlain by greenstones and gabbros, which pass upward into a predominantly chert assemblage. This stratigraphy suggests that the Hozameen Group represents an ophiolite sequence.

(6) An upward-fining stratigraphic succession is recognized in the Lower to Middle Jurassic Ladner Group. These metasedimentary rocks unconformably overlie a greenstone unit of possible Early Triassic age. The lowermost coarse clastic unit in the Ladner Group is economically important as it hosts the Carolin mine deposit (Idaho zone) and many other gold occurrences.

(7) The Pipestem mine mineralization is hosted in fossiliferous wackes which were formerly regarded as belonging to the middle portion of the Ladner Group stratigraphic sequence (Ray, 1983). However, *Buchia* fossils in these wackes are identified as Late Jurassic in age (H. Tipper; J. A. Jeletzky, personal communication) indicating that the host rocks belong to the Dewdney Creek Group, which elsewhere disconformably overlies the Ladner Group (Coates, 1974). Thus some rocks previously assigned to the Ladner Group, including those in the vicinity of Ladner Creek, probably include Dewdney Creek Group metasedimentary rocks. The general absence of megafossils and the similar sedimentary lithologies makes it difficult to distinguish these two groups in the field.

(8) Although gold mineralization throughout the Coquihalla gold belt was generally accompanied by the introduction of silica, usually as quartz veins, the mineralogies, form of occurrence and host rock lithologies are highly variable.

(9) Most minor gold occurrences are associated with thin, irregular, discontinuous quartz veins; at the Emancipation mine and the Monument occurrence, however, the veins are wider (0.5 to 2.5 metres) and more continuous (up to 350 metres).

(10) Most gold mineralization throughout the belt is sulphide poor. However, the mineralization at Carolin mine and the McMaster zone contains up to 15 per cent sulphides, mainly pyrrhotite, pyrite, and arsenopyrite; it is also associated with abundant albite.

(11) A number of regional controls to mineralization in the Coquihalla gold belt are recognized; these include (a) the presence of brittle host rocks suitable for open space facturing, (b) proximity to the East Hozameen fault and the eastern margin of the southern serpentine belt, and (c) proximity to the Ladner Group-greenstone unconformity which is often the locus of brittle shearing. Over 95 per cent of the total gold production from the belt has come from deposits less than 200 metres from the East Hozameen fault and the basal Ladner Group unconformity.

(12) Porphyritic felsic sills intruding the Ladner Group throughout the district are probably related to the Needle Peak pluton, which has been dated at 39 Ma. The age of the mineralization at Carolin mine and elsewhere is unknown; however, sporadic gold hosted in the felsic sills indicates that some gold in the belt is less than 39 Ma in age.

(13) These felsic sills are only found in the Ladner Group which suggests that the major movements along the Hozameen fault system postdate 39 Ma. Geological interpretation indicates that at least 18 kilometres of right lateral transcurrent movement occurred along the Hozameen fault.

(14) The discovery of pyrite-chalcopyrite-molybdenum mineralization in the faulted, thermal metamorphic aureole of what is believed to be the Needle Peak pluton, suggests that this granodiorite body could form a viable exploration target for base and precious metals.

(15) The Hozameen Group, which appears to represent an oceanic ophiolite suite, could form a good regional exploration target for massive sulphide deposits containing gold and/or cobalt.

## ACKNOWLEDGMENTS

The author wishes to thank the management and staff of Carolin Mines Ltd. and Aquarius Resources Ltd. for their active cooperation, particularly D. G. Cardinal, R.J.E. Niels, and J. T. Shearer. Thanks are also expressed to H. Tipper and J. A. Jeletzky of the Geological Survey of Canada for the identification of macrofossil material and to the staff of the Ministry of Energy, Mines and Petroleum Resources' Laboratory for analytical and X-ray work. Constructive criticism by W. J. McMillan and J.W.H. Monger is also gratefully acknowledged, while the fieldwork was helped by the continued excellent performance of P. Desjardins as field assistant.

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# REPORT ON THE EAST PIT OF THE HIGHMONT OPERATION
## (92I/7E)

By W. J. McMillan

## INTRODUCTION

The work described here is based on a three-day visit to the Highmont operation (Fig. 23) this summer. Emphasis both in discussions and during pit examinations was on alteration, metallic mineral zoning, and structural features in order to determine the impact of structural features on ore distribution and to assess the utility of alteration and zoning as grade indicators. Work was mainly on 5270 level, although blast-hole information for 5310 level was considered.

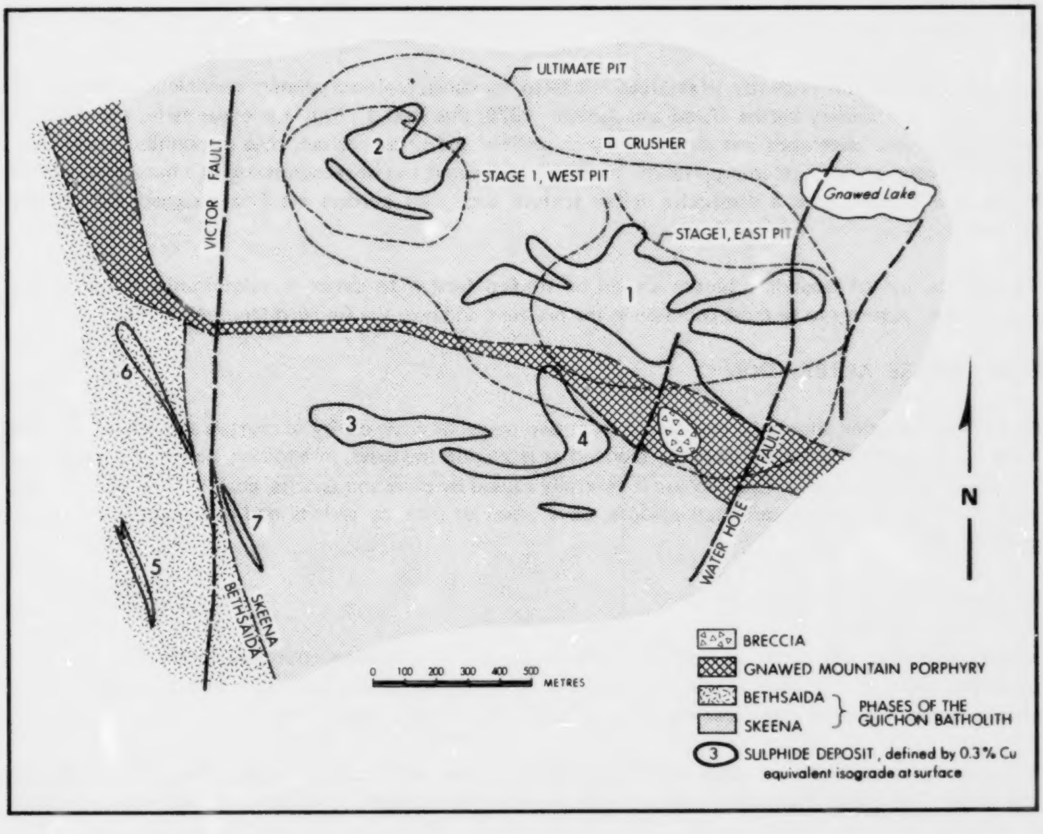

Figure 23. Location map of the Highmont deposit.

## ALTERATION

### INTRODUCTION

The degree of alteration in the rocks is highly variable and closely related to the density of mineralized fractures. Fresh-looking rocks and more altered rocks lie side-by-side; widespread pervasive alteration zones are uncommon. The amount of weak, moderate, and intense plagioclase alteration is important because it indicates the relative intensity of the hydrothermal activity; it may relate to ore grade.

The following alteration sequence is mainly after Reed and Jambor (1976):

| TIMING | ALTERATION | MINERALOGY |
|---|---|---|
| Early | Potassic core and propylitic fringe | Biotite, K-feldspar, chlorite, epidote, albite |
| | Phyllic | Quartz, flaky sericite |
| | Propy-argillic overprint | Sericite, kaolinite, montmorillonite, chlorite, epidote |
| | Argillic | Kaolinite |
| | Propylitic | Chlorite, epidote, albite |
| Late | Calcite, zeolite veins | |

### SECONDARY BIOTITE DISTRIBUTION

Secondary biotite was evidently widespread. It filled fractures, replaced primary hornblende, and formed overgrowths on primary biotite (Reed and Jambor, 1976; this study). This event was early; much of the secondary biotite developed was subsequently chloritized and/or epidotized, thus recognition in thin section often rests on textural interpretation. In hand specimen it can be recognized with a hand lens; altered hornblende crystals have a distinctive felted texture and grain borders are finely ragged, not sharply defined.

The distribution of secondary biotite should be studied further to define its relationship, if any, to ore distribution. It seems to be most common in the ore zone and near the Gnawed Mountain dyke.

### PLAGIOCLASE ALTERATION

Plagioclase alteration should be considered from two points of view; clarity of crystals and colour. On one hand plagioclase changes from glassy to clouded as alteration increases, in addition, colour changes reflect the alteration mineralogy. Grey colour is generally caused by clays and sericite, chalky white by kaolinite, greenish white by sericite-carbonate-epidote, olive green or pink by sericite and carbonate, and emerald green by sericite.

### K–FELDSPAR DISTRIBUTION

K-feldspar is relatively common both as a vein filling and in alteration envelopes in the East Pit. It is most abundant in alteration fringes on veins and fractures; some also occurs in quartz veins or quartz sericite zones. Pervasive K-feldspar alteration of matrix and phenocrysts is rare.

K-feldspar is a shade of pink that is visually distinguishable, with practice, from other pink plagioclase alteration. The other alterations represent either a dusting of hematite or sericite plus carbonate alteration.

Primary K-feldspar is interstitial and 10 to 15 per cent by volume. It survives most alteration but is usually destroyed in olive-green alteration zones.

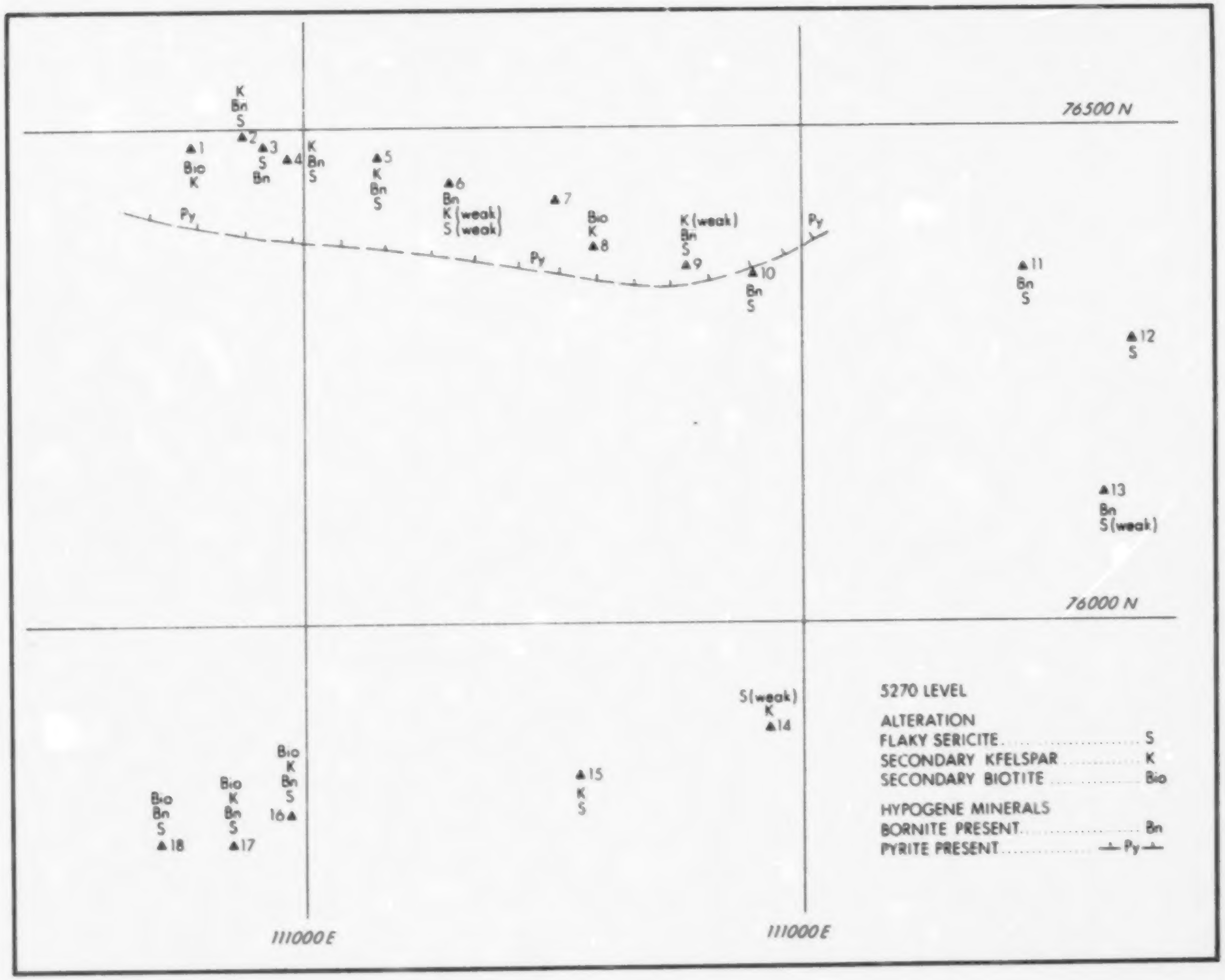

Figure 24. Highmont East Pit, distribution of alteration and hypogene sulphides.

## FLAKY SERICITE DISTRIBUTION

Flaky sericite is common in better grade copper zones and generally present in lower grade zones. In accordance with Reed and Jambor's interpretation (1976) it is a good indicator mineral for ore-grade material. While it does not always itself constitute ore, mineralization in veins and fractures associated with flaky sericite alteration more or less delineates the East Pit orebody (Reed and Jambor, 1976; this study).

Distribution maps show that flaky sericite correlates poorly with molybdenite, unless there is coincident molybdenum and copper enrichment.

## ALTERATION OF MAFIC MINERALS

Chlorite is ubiquitous but the degree of mafic alteration varies; no patterning that would act as ore guides was recognized. Locally, mafics are sericitized; usually in areas with olive-green feldspar alteration.

Epidote occurs in veins, fractures, and as an alteration product in mafic minerals or plagioclase. It is found throughout the deposit but abundance varies; it is not known if it relates to grade distribution. Epidote and chlorite are distributed throughout the ore zone; that is, propylitic alteration characterizes the ore zone. Judging by alteration of early developed biotite, it is a retrograde overprint in the ore zone. Peripheral propylitic alteration, however, was an early event (Reed and Jambor, 1976).

## OTHER ALTERATION MINERALS

Other alteration minerals are actinolite and tourmaline. Actinolite occurs both in fractures and as a replacement of primary amphibole. Tourmaline is fracture-controlled and is an important constituent in breccia zones (*see* Reed and Jambor, 1976).

## HYPOGENE MINERAL ZONING

Hypogene mineral zoning patterns are related to both the Gnawed Mountain dyke and fracture swarms. Although the dyke acted as a heat source, hot fluids probably dominated heat transfer and fracture density-controlled temperature gradients. The rock mass as a whole was hot but post-emplacement temperature was not likely as high as that in hydrothermal veins. Zoning patterns are subparallel to the dyke (*see* Reed and Jambor, 1976). Although the bornite zone occurs mainly in and near the dyke, 'fingers' of it extend out into the pyrite zone. These coincide with zones of higher copper grade that are controlled by northeast fracture swarms, that is, zones with high permeability. Fluids moving outward in these highly permeable zones evidently moved faster and stayed hotter than those in adjacent, less permeable zones.

The relative abundance of bornite relative to chalcopyrite is important in predicting grades and ore trends. The mineralogy and frequency of mineralized veins and fractures are also important. For example, at HE11 (Fig. 24) veins with flaky sericite halos are bornite-rich and constitute ore, even though they comprise only one fracture set.

## HIGHMONT STRUCTURE

### COPPER DISTRIBUTION IN THE EAST PIT

**INTRODUCTION**: Copper contours show very clear trends that relate to several fracture directions (Figs. 25 and 26). However, several interpretations are possible for weaker trends because overlapping patterns become diffuse. Pit mapping indicates (G. Sanford, personal communication) that dominant trends average 025 degrees, 040 to 050 degrees, and 140 to 150 degrees; lesser trends are 075 and 095 degrees.

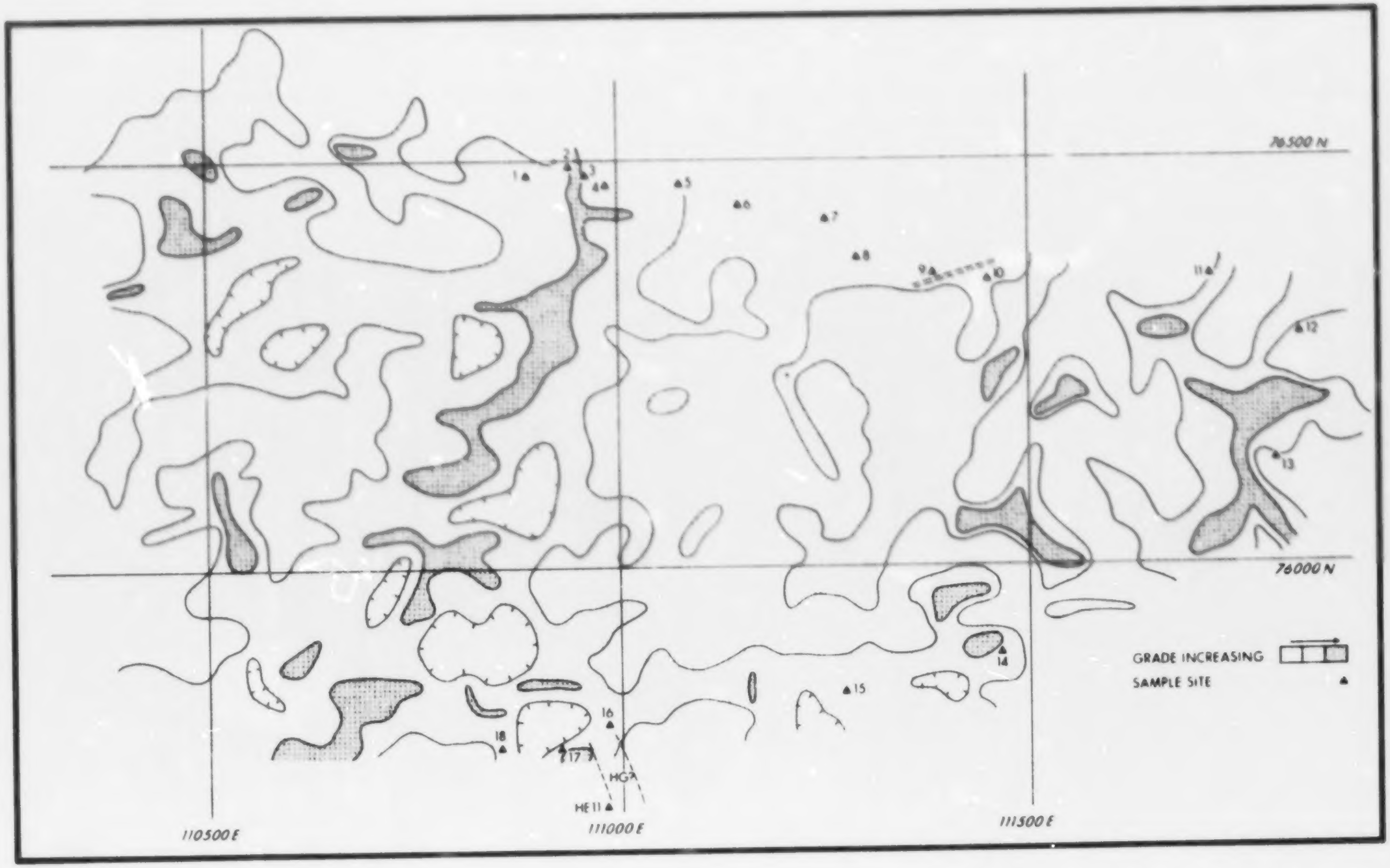

Figure 25. Highmont East Pit, 5270 level, contoured copper values from blast hole assays.

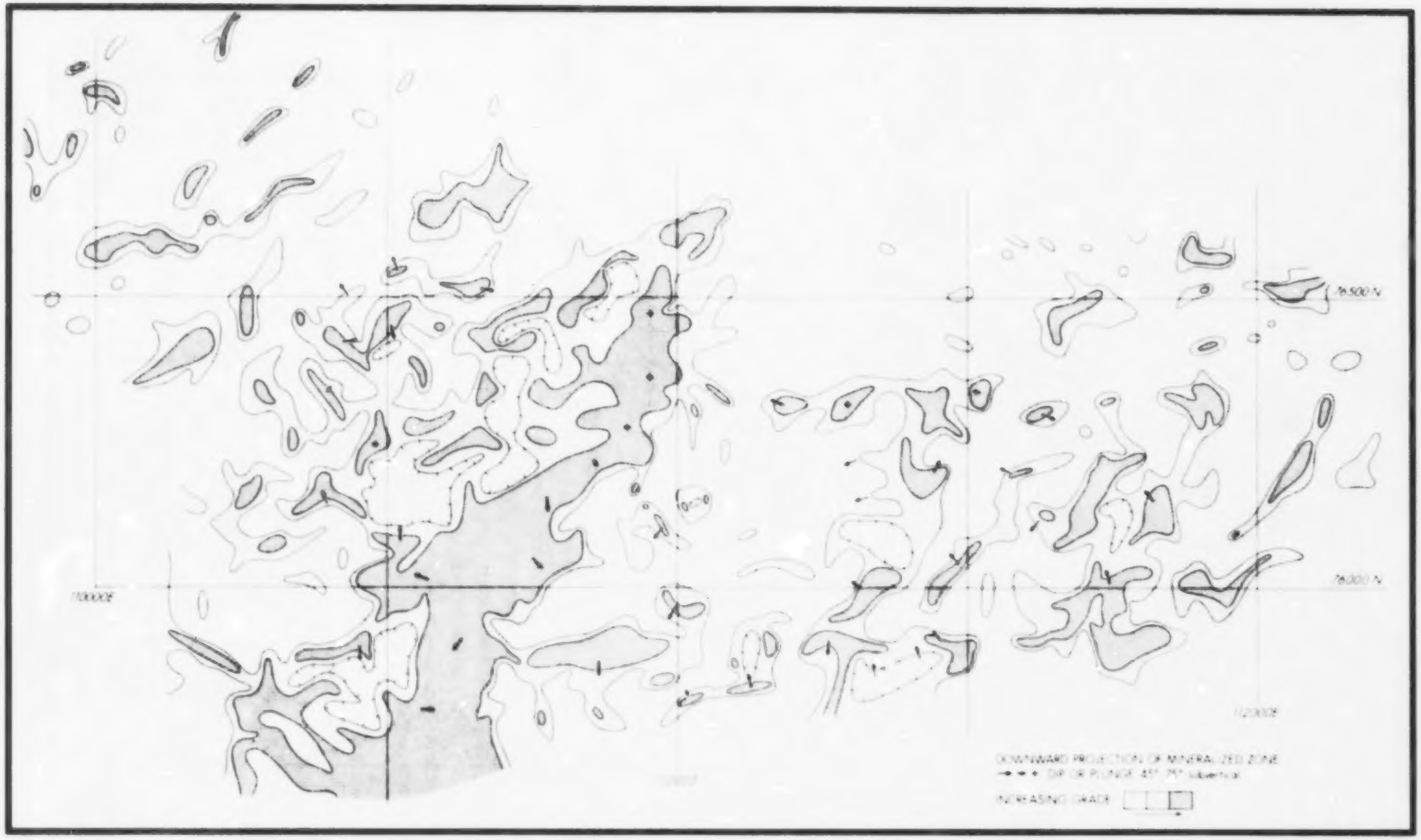
76500 N
76000 N
11000E
12000E
DOWNWARD PROJECTION OF MINERALIZED ZONE
DIP OR PLUNGE 45°, 75°, subvertical
INCREASING GRADE

Figure 26. Highmont East Pit, 5310 level, contoured copper values from blast hole assays.

**COPPER, 5270 LEVEL:** On 5270 level contoured blast-hole assays for copper give patterns that allow more than one interpretation, although dominant elements are common. Two possible interpretations of dominant trends in the patterns are as follows; in degrees azimuth:

Interpretation I (in sequence of relative abundance based on contour patterns only): 035, 060, 120, 090.

Interpretation II (based on patterns and utilizing field information from G. Sanford, personal communication): 025, 140, 060, 090.

Contoured blast-hole assays clearly confirm that mineralized vein and fracture orientations largely control copper grade patterns. However, some anomalies remain; for example, there is a slight discrepancy in azimuth between dominant northeast and southeast trends estimated from blast-hole assays and those measured during pit mapping.

Grade trends on 5270 level confirm strong development of northeasterly oriented, better grade copper zones. From west to east these apparently fan slightly – from 040 to 060 degrees in the west to 030 to 040 degrees centrally and in the east.

This northeast pattern dominates in the central area; it is weaker in the west and weaker still in the east, where southeast-trending fractures are prominent. Consistently, the southeast set trends 115 to 125 degrees across the width of the pit. It seems likely that the northeast fractures are younger; they apparently overprint the southeast set.

Adjacent to and in the Gnawed Mountain dyke grade patterns are elongated and parallel to the borders of the dyke.

The relative importance of fractures trending 140 to 150 degrees is not evident from contoured blast-hole assays.

**COPPER, 5310 LEVEL:** Near the dyke on 5310 level east-west trends predominate. Elsewhere dominant trends are northeast and southeast, subparallel to those on 5270 level (described previously).

**ORIENTATION OF COPPER ZONES:** Copper zones dip, plunge, coalesce, split, and reorient between 5310 and 5270 levels. In spite of the variations though, general trends are fairly consistent. Zones that trend 025 to 035 degrees range in dip from 45 degrees northwest through to subvertical. East-west zones along the Gnawed Mountain dyke have moderate north or moderate south dips; zones trending 060 degrees generally dip about 60 degrees southward. Better grade zones tend to form dipping sheets. Zones trending 120 degrees dip steeply southward and tend to form elliptical pipe-like 'shoots' at junctions with northeast-trending zones; these pipes usually plunge northwestward.

In several instances zones dominated by northeast fractures on 5310 level are dominated by northwest fractures on 5270 level. An example is near 76000N 115000E.

**SUMMARY:** Higher copper grades reflect strong fracturing in a northeast direction; grade patterns indicate interaction of several crossing fracture sets. The fractures are not vertical (G. Stanford, personal communication), so better grade ore zones can be expected to be in the form of dipping sheets or plunging elliptical 'pipes'. Fracture mapping should enable ore trends and plunges to be predicted.

## MOLYBDENITE DISTRIBUTION IN THE EAST PIT

**INTRODUCTION**: Molybdenite occurs with chalcopyrite in thick quartz veins and with chalcopyrite and lesser bornite in fractures and veins. The thick veins generally have an olive-green alteration selvedge several metres in width. As at Lornex, they apparently post-date main-stage mineralization. In the East Pit, veins of this type strike about 030 degrees or 060 to 080 degrees and dip 040 to 060 degrees, usually toward the northwest. Molybdenite is apparently not abundant in the older veins and fractures.

**DISTRIBUTION PATTERNS**: Molybdenite in the East Pit is more restricted in distribution than copper but better grade copper zones (Figs. 25 and 26) correlate reasonably well with better grade molybdenite zones (Figs. 27 and 28).

Locally, particularly along the east side of the pit on 5270 level, molybdenum is concentrated in areas with low copper concentrations. Another such area is near 111250E, 76200N on both 5310 and 5270 levels. Molybdenite values are relatively low near the Gnawed Mountain dyke.

Fracture and vein mineralogy show at least two distinct episodes of molybdenum mineralization. The earlier accompanied chalcopyrite-bornite mineralization; the later occurs in quartz veins with chalcopyrite – some are up to one metre wide.

The thick younger veins may carry spectacular molybdenum values but could be missed if blast-hole drilling was not accompanied by mapping. For example, between sample sites M1 and M2 (Fig. 27) there is a molybdenite vein that strikes 080 degrees and dips 040 degrees northward. Contours drawn only from the blast-hole assay data would not show real grade trends – part of the vein would be designated waste! Similarly, the vein between sites M9 and M10 was intersected by only one blast hole and most of it would show as waste.

On 5270 level molybdenum values are relatively low close to the Gnawed Mountain dyke, especially on the east side of the pit. Dominant fracture systems are apparently northeast (about 025 to 045 degrees) and east-northeast (090 to 095 degrees). Weaker zones are oriented southeast (115 degrees).

The dominant controlling fracture set for molybdenum mineralization on 5310 level trends 030 to 045 degrees. Distribution patterns of molybdenum are complicated by interaction of these and less intense fracture sets at 050 to 060 degrees, 085 to 090 degrees, and 120 to 125 degrees.

These trends correlate closely with those controlling copper mineralization on both 5310 and 5270 levels.

**ORIENTATION OF MOLYBDENITE ZONES**: Molybdenite zones apparently plunge and dip; they narrow slightly from 5310 to 5270 level and zones that are coherent on 5310 level may split on the lower level.

Near Gnawed Mountain dyke, centered on 110600E, 75800N, ameboid zones apparently plunge 30 degrees eastward. Away from the dyke four major northeast-trending zones apparently dip northwest at about 45 degrees. Associated east to southeast-trending fracture systems apparently either dip southwest or are vertical.

## CONCLUSION

The Gnawed Mountain dyke acted as a heat sink that influenced the hydrothermal regime at Highmont. Alteration and hypogene mineral zoning patterns are irregular in detail but subparallel, in general, to the

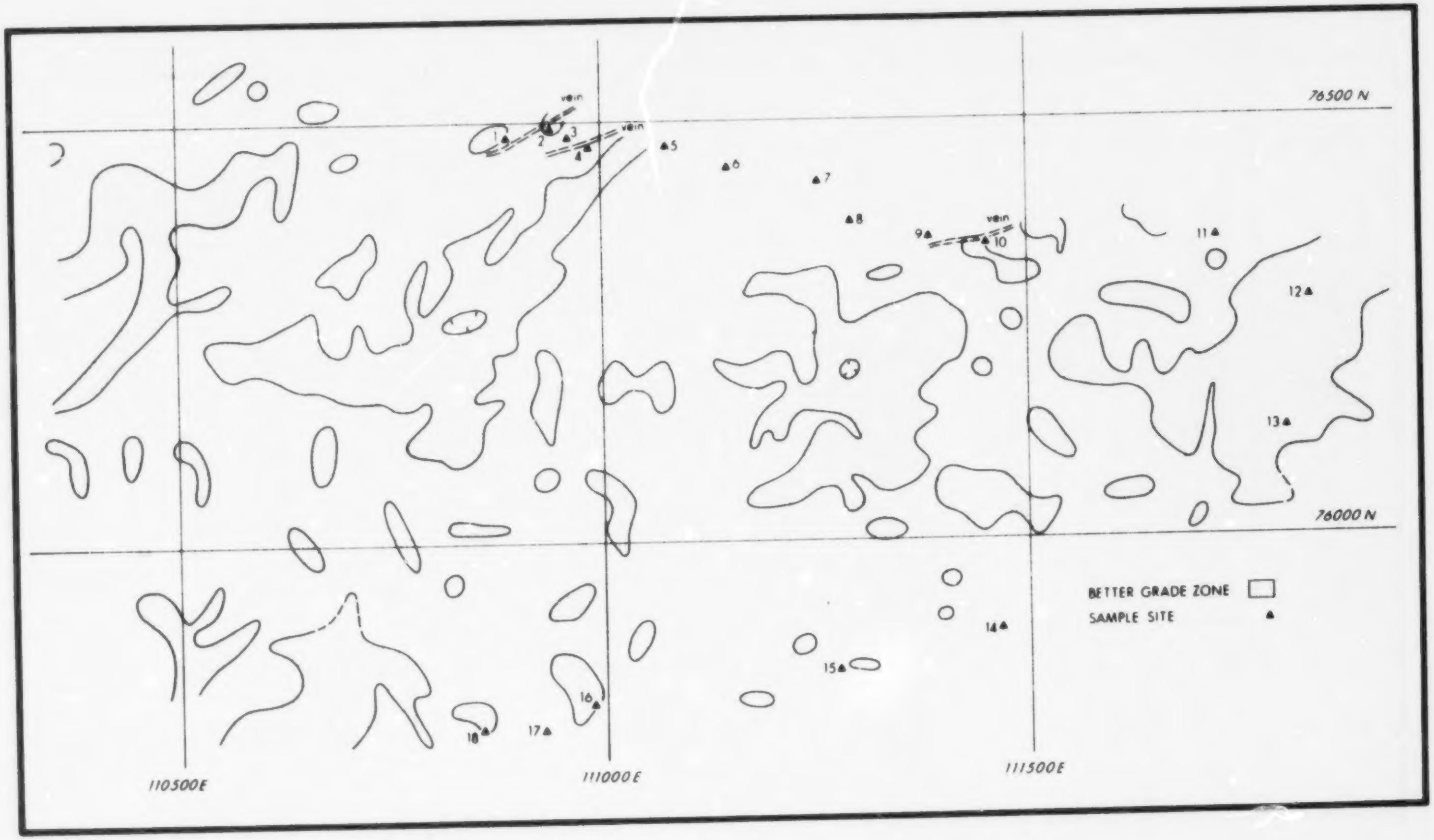

Figure 27. Highmont East Pit, 5270 level, contoured molybdenum values from blast hole assays.

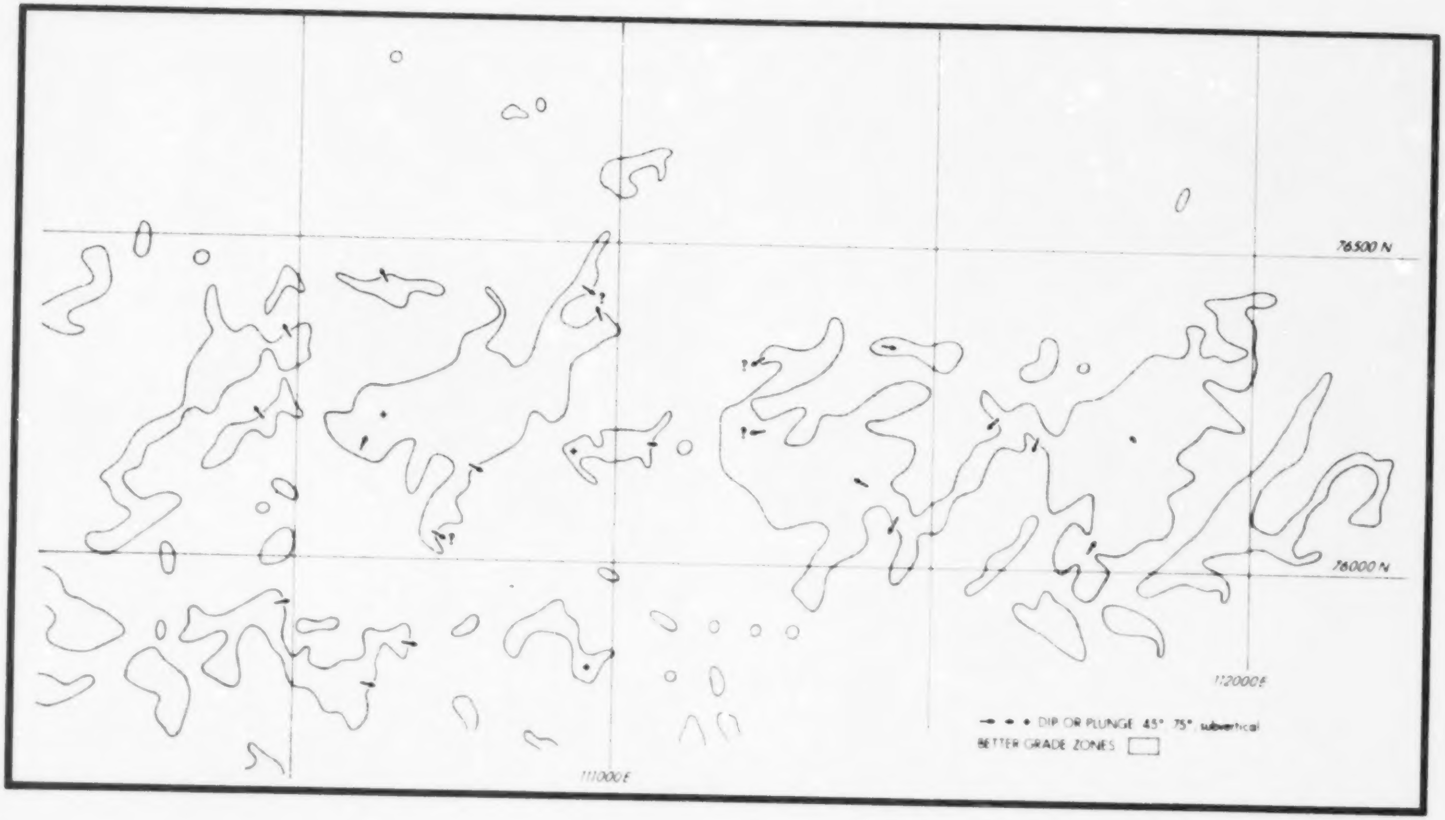

Figure 28. Highmont East Pit, 5310 level, contoured molybdenum values from blast hole assays.

dyke (Reed and Jambor, 1976). Near the dyke bornite is an important ore mineral; away from it chalcopyrite becomes dominant, then there is a weak pyrite 'halo'. Ore grades occur locally in the pyrite halo and parts of the bornite zone are waste. Silicate alteration assemblages were similarly influenced but zones of more intense alteration reflect fracture intensity, hence porosity, more than proximity to the dyke.

Fracture density during mineralization controlled permeability and ore fluid flow paths. Fractures occur in swarms; they are not uniformly distributed. Therefore, grade and alteration patterns, which were controlled by the ore fluids, are irregular in outline and variable in intensity.

Fractures that control ore zones have several orientations and moderate to steep dips. Therefore, ore zones dip and zones that are controlled by intersections of fracture swarms plunge. Careful mapping, particularly of mineralized fracture orientation, density, and mineralogy is needed to enable accurate downward projections of ore zones.

## ACKNOWLEDGMENTS

The cooperation and hospitality of staff at Highmont are gratefully acknowledged; special thanks go to Mine Manager, B. R. Williams; Chief Geologist, L. Tsang; and Pit Geologist, G. Sanford. E. Sadar of the Inspection and Engineering Branch in Kamloops kindly loaned the author a vehicle to facilitate the work.

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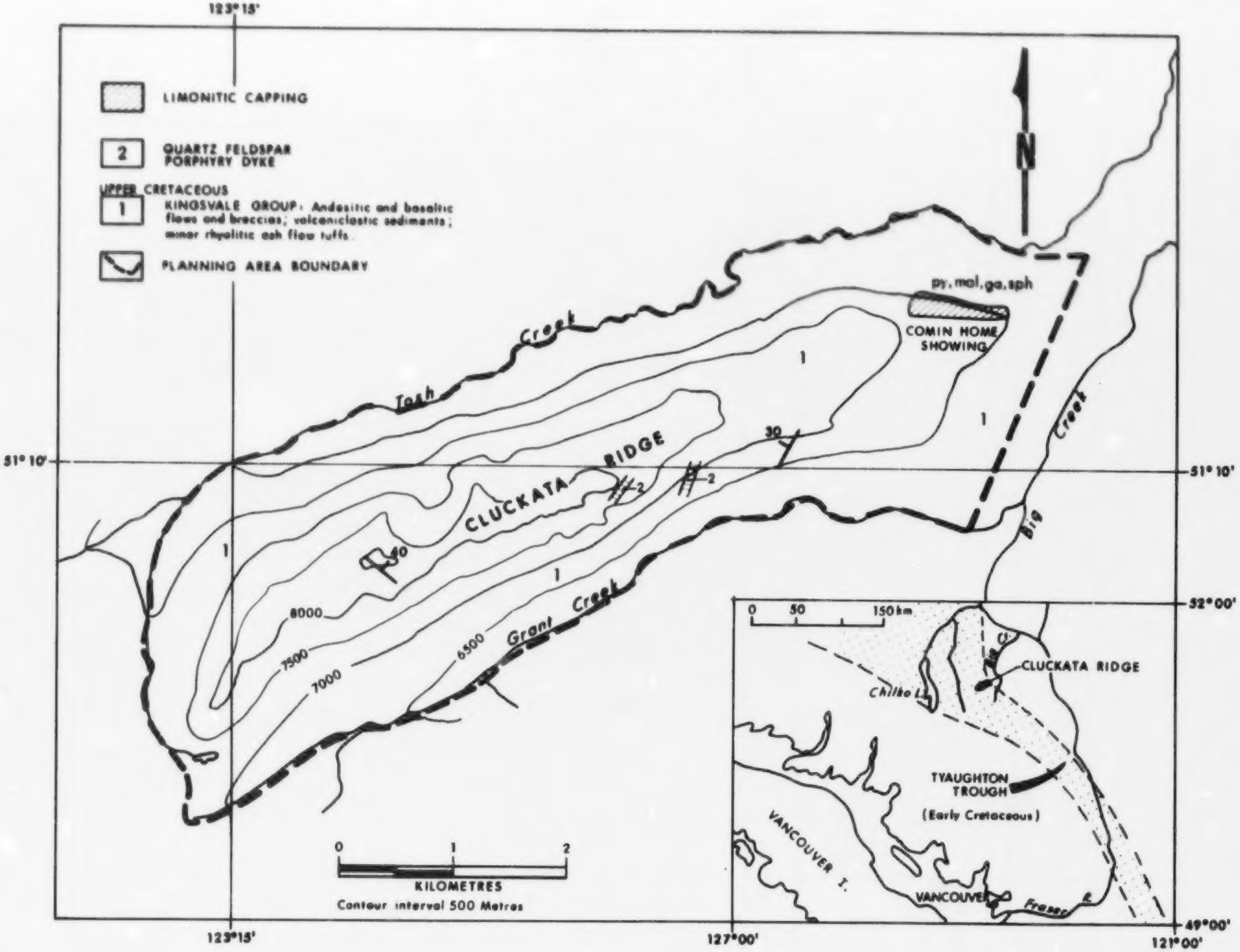

Figure 29. Cluckata Ridge planning area (92O).

# MINERAL EVALUATION STUDY OF THE CLUCKATA RIDGE AREA TASEKO LAKES MAP–AREA

## (92O/3)

By W. R. Smyth

## INTRODUCTION

A half-day reconnaissance of the Cluckata Ridge (Fig. 29) area was made in August 1983 for land use assessment. The entire ridge, encompassing 1 995 hectares, was proposed by the Ministry of Lands, Parks and Housing as an Ecological Reserve to protect subalpine and alpine range land. If approved the area would be alienated from mineral exploration and mining. A large pyritic, limonitic capping, clearly visable from the air, occurs at the northeast end of the ridge. For this reason the mineral reserve request has been denied to allow time for a more detailed assessment of the mineral potential.

## LOCATION AND ACCESS

Cluckata Ridge in Taseko Lakes map-area of south-central British Columbia forms part of the Chilcotin Ranges that occur between the Coast Mountains to the southwest and the Fraser Plateau to the northeast. Cluckata Ridge is bounded by U-shaped valleys occupied by Tosh Creek, Grant Creek, and Big Creek. There is no road access and the nearest helicopter bases are at Lillooet 100 kilometres to the east-southeast and Gold Bridge over 60 kilometres to the south.

## REGIONAL GEOLGY AND PREVIOUS WORK

Cluckata Ridge is part of the Tyaughton Trough, a northwest-trending belt of Upper Jurassic to Upper Cretaceous rocks (Jeletzky and Tipper, 1967). The Taseko Lakes map-area (92O) was mapped at 1:250 000 scale by Tipper (1978) who showed Cluckata Ridge to be dissected by a splay of the Taseko fault. Rocks east of the fault were assigned to the Cretaceous Kingsvale Group and those to the west to the Pioneer Formation of the Upper Triassic Cadwallader Group. Cominco Ltd. carried out reconnaissance mapping in the area in 1973 and discovered a large capping at the northeast end of Cluckata Ridge, called the Comin Home showing. Cominco abandoned their claims in the area in 1975 and hence did not file an assessment report with the Ministry. In 1980, the Ministry released results of a stream sediment survey from Taseko Lakes map-area (BC RGS-3). Samples collected from Tosch Creek and Big Creek are weakly anomalous in arsenic, zinc, copper, and lead. Barrier Reef Resources Ltd. carried out a regional geochemical and geological prospecting program in the area in 1979 and staked claims at the northeast end of Cluckata Ridge. Their assessment reports include a brief description of the Comin Home showing. This mineral occurrence does not appear on the Ministry's Revised Mineral Inventory Map (92O), and its existence was not known to the Mineral Land Use Section until seen in the course of this fieldwork. Barrier Reef Resources surrendered their claims in 1982 and the entire study area is currently open to staking.

## GEOLOGY AND MINERALIZATION

Cluckata Ridge is underlain by a sequence of gently dipping volcanic flows, tuffs, and breccias, with minor amounts of intercalated volcaniclastic rocks. No evidence was found to confirm that a splay of the Taseko fault dissects the ridge; the entire rock sequence is presumed to be part of the Kingsvale Group.

Most of the volcanic flows are andesitic to basaltic in composition. They are green, grey to purple, and generally rusty on weathered surfaces. The flows vary from fine grained to feldspar porphyritic and are commonly vesicular. Locally buff to white, rhyolitic, welded ash flow tuffs are intercalated with the volcanic flows. At the east end of Cluckata Ridge the volcanic rocks are cut by rare quartz feldspar porphyry dykes averaging 2 metres in thickness. The dykes are leached with pale broken surfaces but rusty weathered surfaces.

The map unit of economic interest is exposed on a steep north-facing slope at the east end of the ridge. It consists of a large, leached capping up to 600 metres in length. The rock is deeply weathered, white, fine-grained andesite (?) that has rusty limonite-weathered surfaces; it contains up to 5 per cent pyrite as disseminations and aggregates. The rock is highly porous suggesting some leaching of sulphides. Kaolinization, sericitization, and minor silicification are present. Dawson (1981) reported 'minor galena and pyrite on fracture planes and in narrow quartz stringers'. Cominco reported that material containing pyrite gave gold values up to 0.02 ounce per ton (0.69 gram per tonne) and 0.18 per cent copper; these results were confirmed by Barrier Reef Resources (Dawson, 1981).

No contacts were observed in this study between the leached capping and fresh unaltered andesite which occurs nearby to the west. The capping is similar to that associated with leached quartz feldspar porphyry dykes which cut volcanic rocks on the south side of the ridge 1 kilometre to the southwest. The mineralization is possibly related to subvolcanic intrusive activity which is manifested by the porphyry dykes.

## RECOMMENDATION

The Ecological Reserve request has been denied. Despite the low gold and copper assays the results are considered to be encouraging in view of the highly leached character of the capping. It is hoped that private industry will carry out further studies to evaluate the potential of the mineralization at depth.

## ACKNOWLEDGMENTS

Mr. G. Harden of Cominco is thanked for making available company files on the Comin Home property.

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# THE TELKWA, RED ROSE, AND KLAPPAN COAL MEASURES IN NORTHWESTERN BRITISH COLUMBIA

## (93L, M; 104H)

By Jahak Koo

## INTRODUCTION

Potentially economic coal measures underlie the areas surrounding Telkwa River, Red Rose Creek, and Mount Klappan in northwestern British Columbia. In this report these are referred to as Telkwa, Red Rose, and Klappan coal measures. Recently, they have been attracting keen exploration interest.

The present project began with geological field investigation of the Telkwa coal measures in August of 1982. Preliminary results of the 1982 field work were reported in *Geological Fieldwork, 1982* (Koo, 1983). Investigation of the Telkwa coal measures was continued, together with a geological reconnaissance survey of the Red Rose and Klappan coal measures, during the summer of 1983. The objectives of the investigations were to unravel the stratigraphy, structural development, depositional environments, ages, areal extent, and relationships to surrounding rocks of the coal measures; special attention was paid to their coal seams.

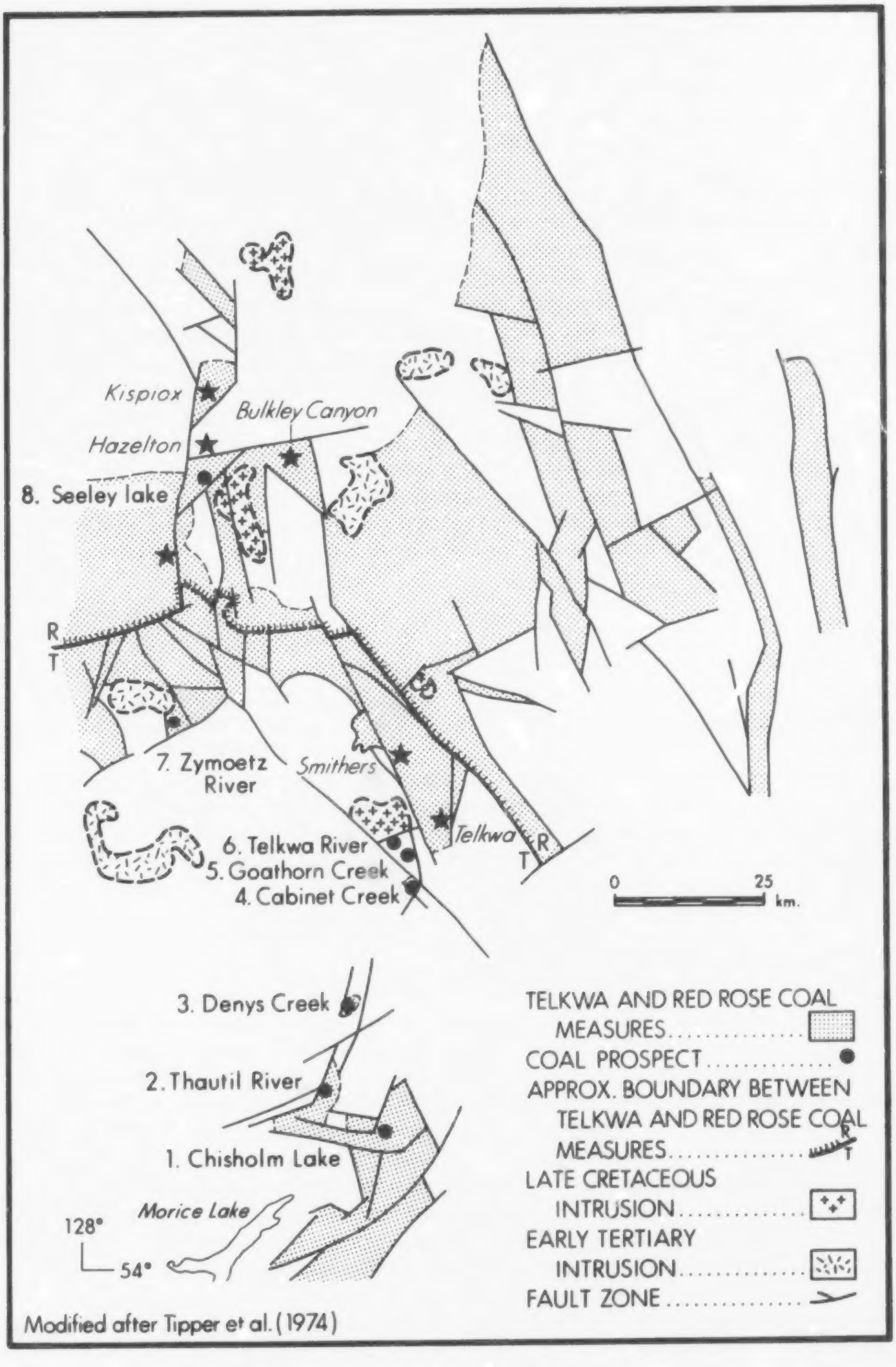
## STRATIGRAPHY

### TELKWA COAL MEASURES

During the intial stage of the present project, Koo (1983) applied the term Telkwa coal measures to the coal-bearing sedimentary sequences exposed at Telkwa River, Goathorn Creek, and Cabinet Creek near the town of Telkwa. The same measures, however, also occur in isolated areas at Denys Creek, Thautil River, Chisholm Lake, and Zymoetz River (Fig. 30). Therefore, coal measures in these other areas are also referred to as Telkwa coal measures in this report. Evidently, these are erosional remnants of the original Telkwa basin which was much more extensive than now.

The Telkwa coal measures can be divided into Lower, Middle, and Upper units (Fig. 31). The Lower unit ranges in thickness from 15 metres to 120 metres. It consists of conglomerate, coarse to fine-grained sandstones, siltstone, claystone, and coal seams. Up to seven fining-up cycles comprise its vertical sections. The individual cycles, each 4 to 40 metres thick, show a lithological variation from conglomerate or coarse-grained sandstone at the base through medium-grained sandstone to fine-grained sandstone and mudstone at the top. In some of the cycles the conglomerates occur near the base of the Lower unit. Most conglomerate layers are 50 centimetres to 15 metres thick; they consist of subrounded clasts that change in size upsection from cobbles through pebbles to granules. The clasts originate mostly from subaerial volcanic rocks of the Early to Middle Jurassic Hazelton Group which underlies the Telkwa coal measures. The coarse to fine-grained sandstones are 10 metres to 40 metres thick; they are similar to the conglomerates in composition. The mudstones have a thickness from 2 to 25 metres. The mudstone layers that are closely associated with coal seams near the top of the Lower unit are relatively thicker.

The Middle unit consists of 90 to 140 metres of medium to fine-grained sandstones and mudstones. Their layers are relatively thick, up to 100 metres, and extend for distances greater than 1 kilometre. Locally, several 2 to 20-metre-thick, fining-up cycles characterize the Middle unit. They begin with medium-grained



Modified after Tipper et al. (1974)

Figure 30. Distribution of the Telkwa and Red Rose coal measures.

sandstone and end with fine-grained sandstone to mudstone. Coal fragments and thin coal seams up to a few centimetres thick occur in this unit. However, intensely bioturbated sandstone and mudstone layers with marine molluscan faunas are dominant in the Middle unit.

The Upper unit consists of more than 330 metres of sandstones, mudstones, and coal seams. The lower part of this unit consists of up to 180 metres of medium to fine-grained sandstones, mudstones, and coal seams. Up to eight cycles make up the lower succession of this unit; each cycle shows a lithological variation from medium-grained sandstone at the base through fine-grained sandstone to mudstone and coal seams. Individual cycles are 10 to 30 metres thick. The upper part of this unit is thicker than 150 metres and consists of mudstone layers with minor amounts of fine to medium-grained sandstones and marl. Several fining-up cycles and varves occur in this unit.

## RED ROSE COAL MEASURES

These coal measures are named after the coal-bearing Red Rose Formation. The Red Rose Formation consists of Late Jurassic and Early Cretaceous marine and nonmarine sedimentary sequences exposed south of Red Rose Creek in the Rocher Deboule Range near the town of Hazelton (Sutherland Brown, 1960). The lowermost member of the Red Rose Formation is a coal-bearing, nonmarine sequence that is greater than 750 metres thick. It is overlain by a shale and siltstone sequence 1 210 metres thick of probable marine origin.

The Red Rose coal measures have been most intensively explored at the Seeley Lake coal prospect; the stratigraphy can be best documented there (Figs. 30 and 31). They also occur in Kispiox Valley, Bulkley Canyon, and Skeena Crossing. A minimum 200-metre-thick sequence of coal measures occurs at the Seeley Lake prospect. The sequence consists of conglomerates, coarse to fine-grained sandstones, mudstones, and coal seams. Up to 25 fining upward cycles characterize vertical sections of the sequence. Individual cycles are 0.3 to 22 metres thick; they vary from conglomerate or coarse-grained sandstone at the base through medium-grained sandstone to fine-grained sandstone and mudstone at the top. Congomerates consist of subrounded, black to grey chert or volcanic clasts which are well sorted in size and grade from 1 centimetre to 2 millimetres upward in the section. Conglomeratic layers vary from 0.2 to 3 metres in thickness; they occur most commonly in the lower parts of the sequence. The coarse-grained sandstones are 0.2 to 1 metre thick and light grey in colour. The medium to fine-grained sandstones are grey or nearly black, and their layers range in thickness from 0.3 to 16 metres. The mudstones are dark grey or black and 0.3 to 15 metres thick. The black mudstones or fine-grained sandstones are closely associated with coal seams.

## KLAPPAN COAL MEASURES

The Klappan coal measures are well exposed at Mount Klappan and in its neighbouring area (Fig. 32). They are greater than 350 metres thick and can be divided into Lower, Middle, and Upper units (Fig. 33).

The Lower unit consists of coarse to fine-grained sandstones, mudstones, and coal seams. Its thickness ranges from 150 metres to 200 metres; its base has not yet been clearly determined. It differs from Telkwa and Red Rose because cycles coarsen upward; up to seven coarsening-up cycles characterize most of its vertical sections, and individual cycles vary in thickness from 1 metre to 30 metres. Each cycle changes from fine-grained sandstone to mudstone and coal seams at the base through to coarse-grained sandstone at the top. Thinly laminated successions of fine-grained sandstone and mudstone occur in some parts of the Lower unit. They are up to 15 metres thick and contain marine molluscan faunas. The laminae are commonly 1 millimetre to 15 centimetres thick; intense bioturbation is common. Angular rip-up clasts of black fine-grained sandstone or mudstone, up to 5 centimetres across, are common within coarse to fine-grained sandstones in upper parts of the cycles. The latter sandstones are generally oxidized and brown in colour.

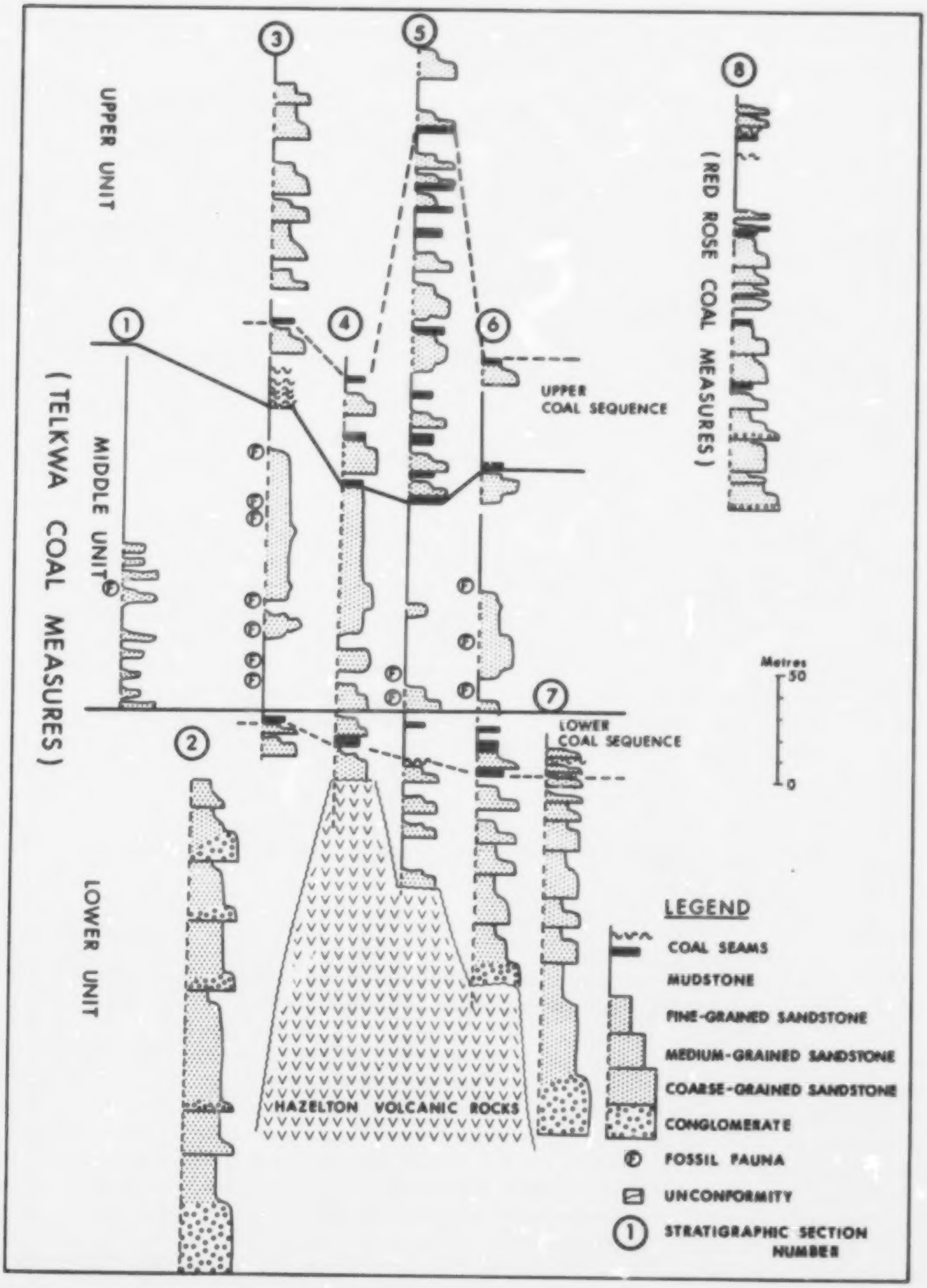


Figure 31. Stratigraphic sections of the Telkwa and Red Rose coal measures.

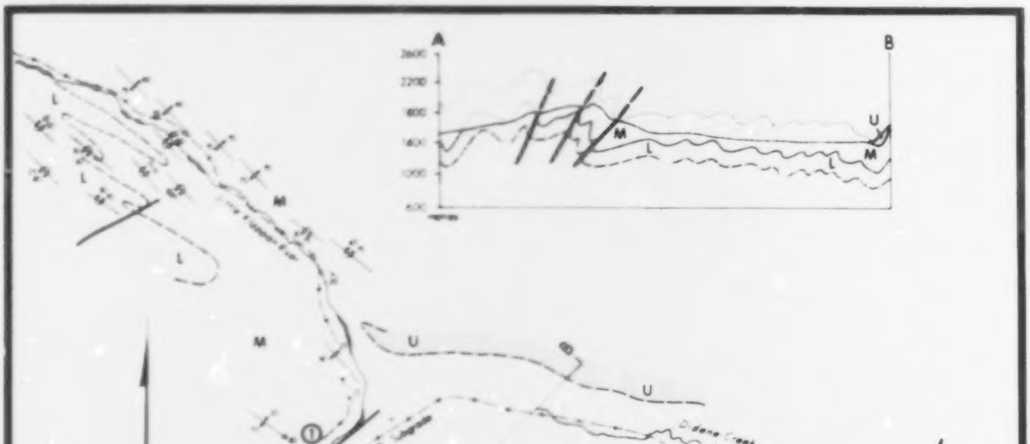


Figure 32. Simplified geology of the Mount Klappan area.

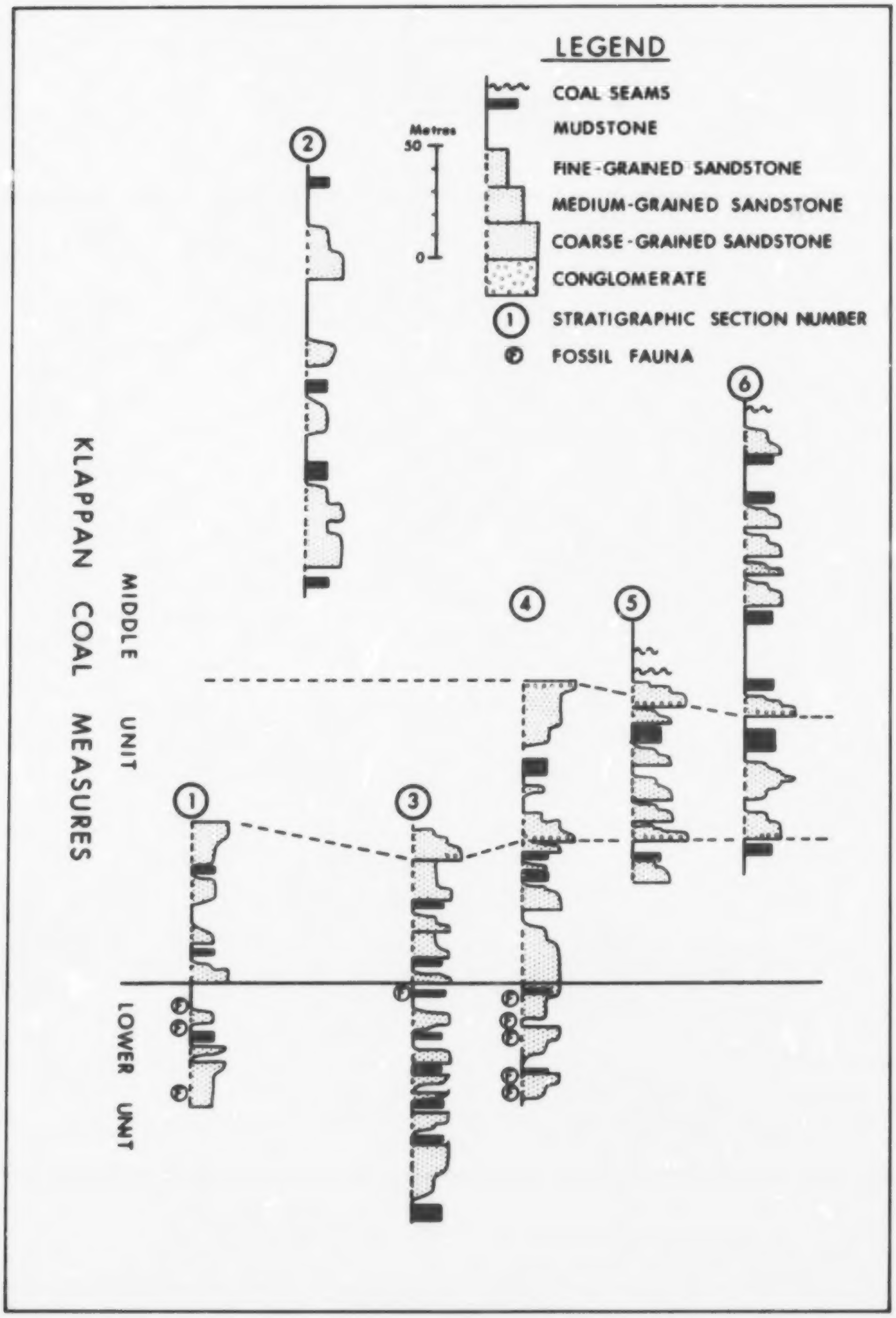


Figure 33. Stratigraphic sections of the Mount Klappan coal measures.

The Middle unit is 320 metres thick and can be subdivided into three zones. The lower zone, 35 to 75 metres thick, consists of coarse to fine-grained sandstones and mudstones; coal seams occur with the mudstone layers. This zone is transitional between the Middle and the underlying Lower units. It consists of up to 10 fining-up cycles that range in thickness from 1 metre to 20 metres.

The middle zone is 150 metres thick and consists of several fining-up cycles. The cycles are 2 to 45 metres thick and vary from chert pebble conglomerate or chert-pebbly sandstones at the base through medium-grained sandstone to mudstones at the top. Coal seams occur with the mudstones. The chert pebble conglomerates or sandstones are up to 15 metres thick.

The upper zone is 95 metres thick; it contains up to 20 fining-up cycles. The individual cycles range in thickness from 1 metre to 35 metres. They are made up of medium-grained sandstones at the base that grades through fine-grained sandstones to mudstones at the top. The mudstones are closely associated with coal seams. Scours, mud cracks, and brown oxidation bands are common in the Middle unit.

The Upper unit consists of medium to fine-grained sandstones, siltstones, claystones, coaly mudstones, and marl. The top has not been clearly defined; however, this unit appears to range in thickness from 150 metres to 200 metres. Varves are common and there are several fining-up cycles. Coal seams, up to 50 centimetres thick, occur with some coaly mudstone layers.

## COAL SEAMS

Coal seams occur in the upper zone of the Lower unit and in the lower zone of the Upper unit within the Telkwa coal measures; these two zones are the lower and upper coal sequences (Fig. 31). Up to four coal seams, 1 to 15 metres apart, occur in the lower sequence. They range in individual thickness from 1 to 6 metres and have an aggregate thickness of 2 to 12 metres. The lower coal sequence varies from 2 to 40 metres in thickness. The upper sequence comprises up to 15 coal seams; they occur in the lower part of the Upper unit. Individual coal seams are 2 to 20 metres apart; these spacings almost correspond to the thickness of individual fining-up cycles. The coal seams range from 1 to 5 metres in thickness with aggregate thickness up to 26 metres. The upper coal sequence ranges from 20 to 170 metres in thickness.

The Red Rose coal measures at the Seeley Lake prospect (Fig. 31) comprise at least six coal seams, 0.3 to 27 metres apart. Individual seams range up to 1.5 metres and aggregate zones up to 5 metres in thickness. The coal sequence at Seeley Lake represents only a partial section of the Red Rose coal measures, therefore more coal seams may occur stratigraphically above and below it.

The Klappan coal measures contain potentially economic seams in their Lower and Middle units (Fig. 33). The Lower unit comprises up to six coal seams, 17 to 30 metres apart. Their individual thickness ranges from 1 to 5 metres with an aggregate thickness of up to 10 metres. The Middle unit contains 10 coal seams; its lower zone has two seams, 4 to 30 metres apart, and they are 1 to 5 metres thick with an aggregate thickness of up to 7 metres. Four coal seams, 8 to 35 metres apart, occur in the middle zone of the Middle unit. They are 2 to 10 metres thick with an aggregate thickness of up to 22 metres. There are four coal seams, 10 to 90 metres apart in the upper zone of the Middle unit. They are 3 to 8 metres thick with an aggregate thickness of up to 22 metres.

Bituminous coal characterizes Telkwa coal seams. Coal in the Red Rose coal measures, however, varies in rank from bituminous to anthracite. The higher rank Red Rose coal occurs in localities where there is tight folding and intrusion of Middle to Late Cretaceous granodiorite and quartz monzonite stocks. For example, Sutherland Brown (1960) documented a thermal aureole that is up to 1.5 kilometres wide around the Rocher Deboule stock. Higher ranked anthracite of the Seeley Lake prospect was produced by thermal metamorphism of Red Rose coal measures marginal to the Rocher Deboule stock. Anthracite also characterizes the Klappan coal seams.

## DEPOSITIONAL ENVIRONMENTS AND AGES

The Telkwa coal measures represent a variety of sedimentary environments. The Lower unit consists of fluvial clastic sediments deposited on a terrane which was initially irregular but subsequently underwent multiple stages of pedimentation and peneplanation. The conglomerates and coarse-grained sandstones form lenticular layers with limited lateral extent; they represent high energy, channel-fill deposits. The medium to fine-grained sandstones and mudstones form relatively extensive layers; they represent low energy, floodplain or meandering drainage plain deposits. Coal swamps of the lower coal sequence formed during the periods of extensive floodplain development. The floodplain deposits are generally mud cracked and oxidized.

Sediments of the Middle unit represent shallow marine transgressions and regressions. The marine transgressions are indicated by sandstone and mudstone layers with marine molluscan faunas; the regressions are marked by thin, cyclic coal-bearing sequences that represent local fluvial deposits.

The lower contact of the Upper unit marks a widespread regression. It begins with a fluvial succession that gives way upward largely to a lacustrine sequence except for local minor marine transgressive facies. Fining-up cycles within the fluvial succession represent meandering channel-fill and floodplain deposits. Eutropic coal swamps developed locally on the floodplains at up to 15 sedimentary horizons.

The Red Rose coal measures are a fluvial sequence composed of channel-fill and floodplain deposits. Coal swamps also developed along with the floodplains.

Hacquebard, *et al.* (1967) determined plant fossils of the Telkwa coal measures to be of Early Cretaceous age. Sutherland Brown (1960) noted that the Red Rose Formation is probably of Late Jurassic and Early Cretaceous age. Tipper and Richards (1976) concluded that the coal-bearing sequences at Telkwa River and Red Rose Creek both belong to the Early Cretaceous sedimentary sequence of the Skeena Group. The sediments were derived from an easterly source, probably during uplift of the Omineca Crystalline Belt (Eisbacher, 1981).

Except for the lower Telkwa coal measures, both Telkwa and Red Rose coal measures contain significant amounts of detrital muscovite and quartz. These support the suggestion that the Omineca Crystalline Belt was a major source for detritus in most parts of the coal measures. However, sediments of the lower Telkwa coal measures are derived from underlying Hazelton volcanic rocks. Tipper and Richards (1976) showed that the Howson and Telkwa Ranges were centres of Hazelton subaerial volcanism and subsequently uplifted to form the southwest Skeena Arch during Jurassic time. During Early Cretaceous time, erosion of the Hazelton volcanic terrane in the ranges provided a local source of sediments for the lower Telkwa coal measures.

The Klappan coal measures consist of shallow marine, fluvial, and lacustrine deposits. The Lower unit was deposited in a transitional zone between marine and continental environments. The sedimentary succession represents progradation of alluvial fans and coal swamps over deltas during a marine regression. The Middle unit was deposited as a fluvial succession. The fining-up cycles containing the coal seams in the Middle unit represent meandering channel-fill, floodplain, and coal swamp deposits. The Upper unit is characterized by meandering channel, overbank, and ephemeral lake deposits.

Malloch (1914) concluded that coal measures in the Groundhog coalfield should be grouped as the Skeena series of Early Cretaceous age. Eisbacher (1974) argued that all major coal seams in the northeastern Bowser Basin occur in the 500-metre-thick Groundhog-Gunanoot facies of Latest Jurassic to Early Cretaceous age and that the coal-bearing facies is overlain by Early Cretaceous Jenkin's Creek facies that consists of continental fine-grained clastics and thin carbonate lenses. Richards and Gilchrist (1979) described strong similarities between the Gunanoot assemblage and the Early to Middle Cretaceous Skeena Group. The lower and middle Klappan coal measures correlate with the Groundhog-Gunanoot facies of the Gunanoot assemblage; the upper Klappan coal measures correlate with the Jenkin's Creek facies.

Widespread conglomerates in the Telkwa, Red Rose, and Klappan coal measures suggest active pedimentation across the Skeena Arch and west of the Omineca Crystalline Belt. The multiple cycles in the coal measures suggest periodic uplift followed by erosion of the Omineca Crystalline Belt. The occurrence of coal seams in mudstone zones near the tops of the cycles suggests that coal swamps formed largely during tectonically quiescent periods in the Omineca Crystalline Belt.

The Telkwa, Red Rose, and Klappan coal measures comprise mainly limnic and telmatic coal deposits. However, they may also contain some paralic coal due to local marine incursions near the top and bottom of the middle Telkwa coal measures, at the top of the Red Rose coal measures, and in the lower Klappan coal measures.

## DEFORMATION

Faults disrupt the Telkwa and Red Rose coal measures (Fig. 30). They trend predominently northwesterly; however, some trend northeasterly to easterly. They dip mostly at high angles ranging from 70 to 90 degrees and show normal or reverse displacements of up to several kilometres. The coal measures commonly occur in the grabens which occupy low-lying poorly exposed areas. This type of structural setting is best exemplified by the Telkwa coalfield (Koo, 1983). The northwesterly trending faults are of Late Cretaceous and Early Tertiary age; the northeasterly to easterly trending faults are of Late Tertiary age (Carter, 1981).

Gentle bedding dips are common and broad open folds are developed in the Telkwa and Red Rose coal measures where dips range from 5 to 25 degrees northeast or southwest. However, tight folds also occur in localities where the coal measures are intruded by Cretaceous and Tertiary stocks. The tight folds are cut by the intrusions and by northwesterly trending thrust faults. Younger northwesterly trending high angle faults cut the folds, the thrust faults, and the intrusions. The folds and thrust faults are apparently of Middle Cretaceous age.

The Klappan coal measures show open to tight folds (Fig. 32) that are almost vertical or overturned to the northeast. The fold axes strike north 30 to 60 degrees west; their axial planes dip 25 to 85 degrees southwest. Most of the folds are asymmetrical; many are cut by thrust faults with maximum displacements of 150 metres. The thrust faults strike north 20 to 40 degrees west and dip 10 to 25 degrees southwest. These faults commonly have associated chevron, kink, or concentric style dragfolds. All folds and the thrust faults are cut by high angle faults that trend northerly or northwesterly. These high angle faults are themselves cut by easterly to northeasterly trending high angle faults. Richards and Gilchrist (1979) report that major faults in the Groundhog coal area immediately south of Mount Klappan also trend northwesterly or easterly.

## CONCLUSIONS

The Telkwa, Red Rose, and Klappan coal measures consist mainly of fluvial clastic sequences with minor shallow marine and lacustrine sedimentary successions. Economic coal seams developed mainly in the fluvial sequences. The shallow marine successions comprise coastal beach, tidal flat, and lagoonal deposits. They appear to represent mainly regressive facies with local irregular transgressive facies.

All three coal measures are nearly isochronous and may be referred to collectively as the Early Cretaceous Skeena coal measures. Tectonic uplift of the Omineca Crystalline Belt largely controlled sedimentation of the coal measures, although locally the southwestern Skeena Arch also influenced deposition of the lower Telkwa coal measures.

The three coal measures were subjected to a minimum of four phases of deformation: open to tight folds; thrust faults; northwesterly high angle faults; and northeasterly high angle faults.

The coal measures contain economic coal seams of limnic, telmatic, and paralic origin. Their ranks range from bituminous to anthracite coal. The higher rank coal occurs in areas of tight folding and adjacent to Middle to Late Cretaceous intrusions.

## ACKNOWLEDGMENTS

Thanks are extended to: B. Ryan, D. Handy, and S. Cameron of Crows Nest Resources Ltd.; L. Gething of Bulkley Valley Collieries Limited; D. Plecash of D. Groot Exploration; and G. Childs, B. Flynn, and C. Williams of Gulf Canada Resources Inc. for their willing cooperation; and L. Rowan for his field assistance.

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# AG PROSPECT
## (93M/7W)

By T. G. Schroeter

## INTRODUCTION

The AG (Mineral Inventory 93M-13) (formerly Sue, Red, Foss) prospect, consisting of 6 units, is located 60 kilometres north of Smithers, approximately 5 kilometres northwest of French Peak. Access is by helicopter from Smithers. In July 1983, Golden Gate Exploration Ltd. completed eight diamond-drill holes totalling approximately 610 metres.

## HISTORY

In 1964 Falconbridge Nickel Mines Limited staked the Red claims; during 1964 to 1965 they conducted geological surveys and a self-potential survey and stripped an area approximately 40 metres by 18 metres. In 1973, Canadian Superior Exploration Limited conducted a geochemical survey. In 1980, Doug Whelan sampled the property; it is now owned by Golden Gate Exploration Ltd.

## GEOLOGY AND MINERALIZATION

The property is underlain by arkosic and argillaceous tuffaceous sandstones and argillites of the Hazelton Group which have been intruded by Cretaceous (?) sills of feldspar porphyry.

Pyrrhotite, chalcopyrite, pyrite, marcasite, arsenopyrite, tetrahedrite, sphalerite, galena, stibnite, and owyheeite ($Pb_5Ag_2Sb_6S_{15}$) occur as replacement veins (up to 1 metre in width) with quartz-carbonate ± tourmaline gangue. Sphalerite appears to be late stage, as are veinlets of calcite and siderite. Two main areas of mineralization are known:

(1) **Hepworth Creek**
A strong lineament that runs up Hepworth Creek has a 1.2-metre to 1.8-metre shear zone in it striking 135 degrees with a near vertical dip. Branching veins of massive sulphide are up to 37 centimetres wide; adjacent fine sulphide disseminations may extend into the wallrock for as much as 60 centimetres. Veins strike at 120 degrees and are vertical.

(2) **Boomer Creek**
A 0.3-metre quartz vein with owyheeite and tourmaline occurs approximately 45 metres south of the junction of Hepworth and Boomer Creeks (Fig. 34).

Gold values in excess of 0.1 ounce per ton and silver values in excess of 40 ounces per ton have been obtained (unpub. company report, 1983).

## ACKNOWLEDGMENTS

The writer would like to thank Barry Price, Consultant for Golden Gate Exploration Ltd., for providing access to the property and hospitality while on the property.

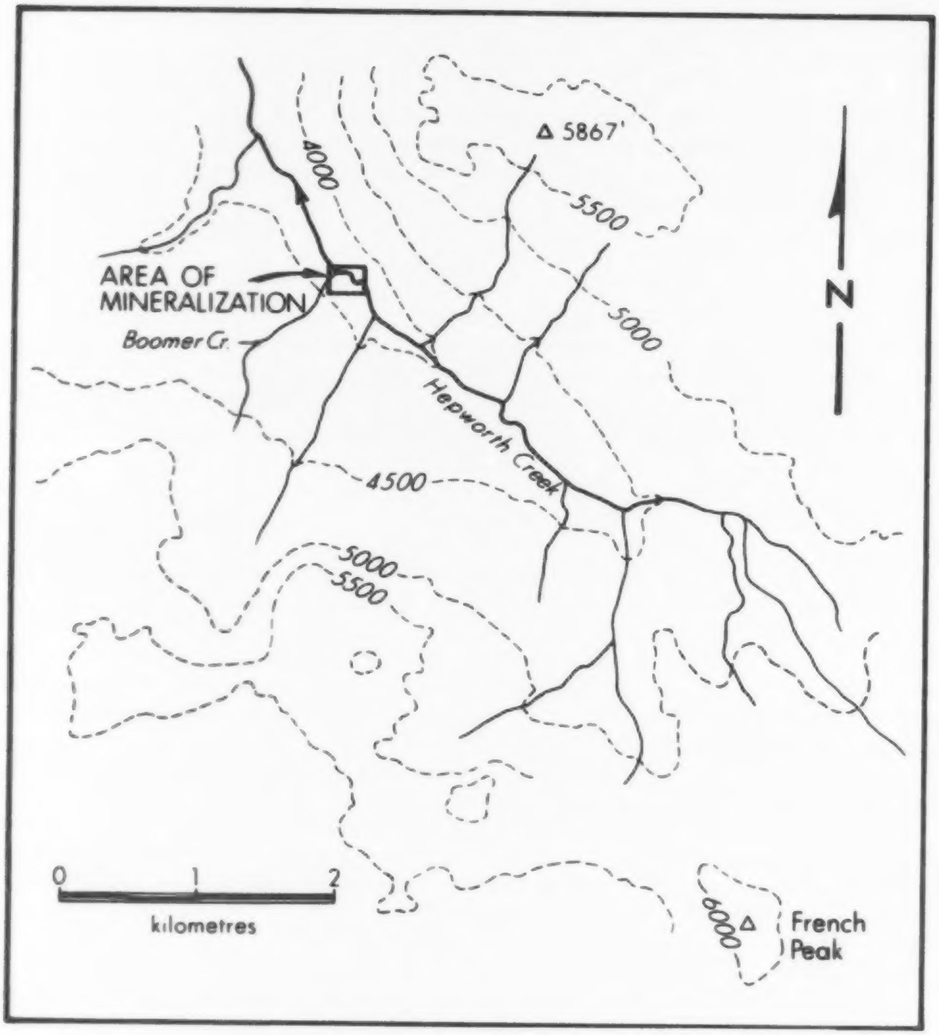


Figure 34. Location map for the AG prospect (93M/7W).

# REGIONAL GEOCHEMICAL SURVEYS HAZELTON AND MANSON RIVER MAP–AREAS

## (93M, N)

By H. R. Schmitt

The British Columbia Ministry of Energy, Mines and Petroleum Resources was involved in two regional geochemical surveys in 1983, covering map-areas 93M and 93N.

The Ministry funded and supervised the geochemical survey for 93M (Hazelton) and provided supervision for the Federal Department of Energy, Mines and Resources' funded geochemical survey of 93N (Manson River). Completion of analytical work and data compilation is expected by late May 1984. Results of the surveys, in the form of sample location maps and analytical data sheets, will be released in early June. Simultaneous data release is anticipated to take place in Smithers, Vancouver, and Victoria.

To date a total of 19 map-areas has been sampled in British Columbia for a total coverage of approximately 250 000 square kilometres; average sample density ranges from one site per 12.5 square kilometres to one site per 15 square kilometres (Fig. 35).

Field sampling in 1983 was carried out in the Hazelton map-area (93M) by Bema Industries Limited and in Manson River map-area (93N) by Hardy Associates (1978) Limited. Both surveys covered relatively remote areas and relied primarily on helicopter support with limited use of truck and boat. Helicopter services by Quasar Aviation Limited were used by Bema Industries and Viking Helictopers Limited provided service for Hardy Associates. Field supervision for the Ministry and Geological Survey of Canada was by H. R. Schmitt.

Both surveys were concluded successfully within the alloted budget and schedule. NTS 93M, covering 14 000 square kilometres, was sampled in 1 040 sites for an average coverage of one sample per 13.46 square kilometres. NTS 93N, covering 14 000 square kilometres, was sampled in 1 062 sites for an average coverage of one sample per 13.18 square kilometres. Thirty samples collected in 93N were unsuitable for analyses and might be recollected.

Sample preparation and analyses were contracted to commercial firms. Water samples were analysed for uranium, fluorine, and pH by Acme Analytical Laboratories. Stream sediments will be analysed for zinc, copper, lead, nickel, cobalt, silver, manganese, iron, arsenic, molybdenum, tungsten, mercury, uranium, and antimony by Chemex Laboratories.

The two contiguous surveys cover diverse geological terranes, containing several significant mineralized environments. Placer and vein-type gold and silver mineralization is providing focus for intense exploration activity in Manson Creek area and along the Pinchi and Vital faults. Exploration in Hazelton map-area (93M) is primarily for polymetallic vein deposits, with limited exploration for copper-molybdenum porphyry deposits. Survey results are anticipated to reinforce current exploration activity and provide valuable regional geochemical information for the reinterpretation of mineral potential in apparently less mineralized and overburden-covered areas.

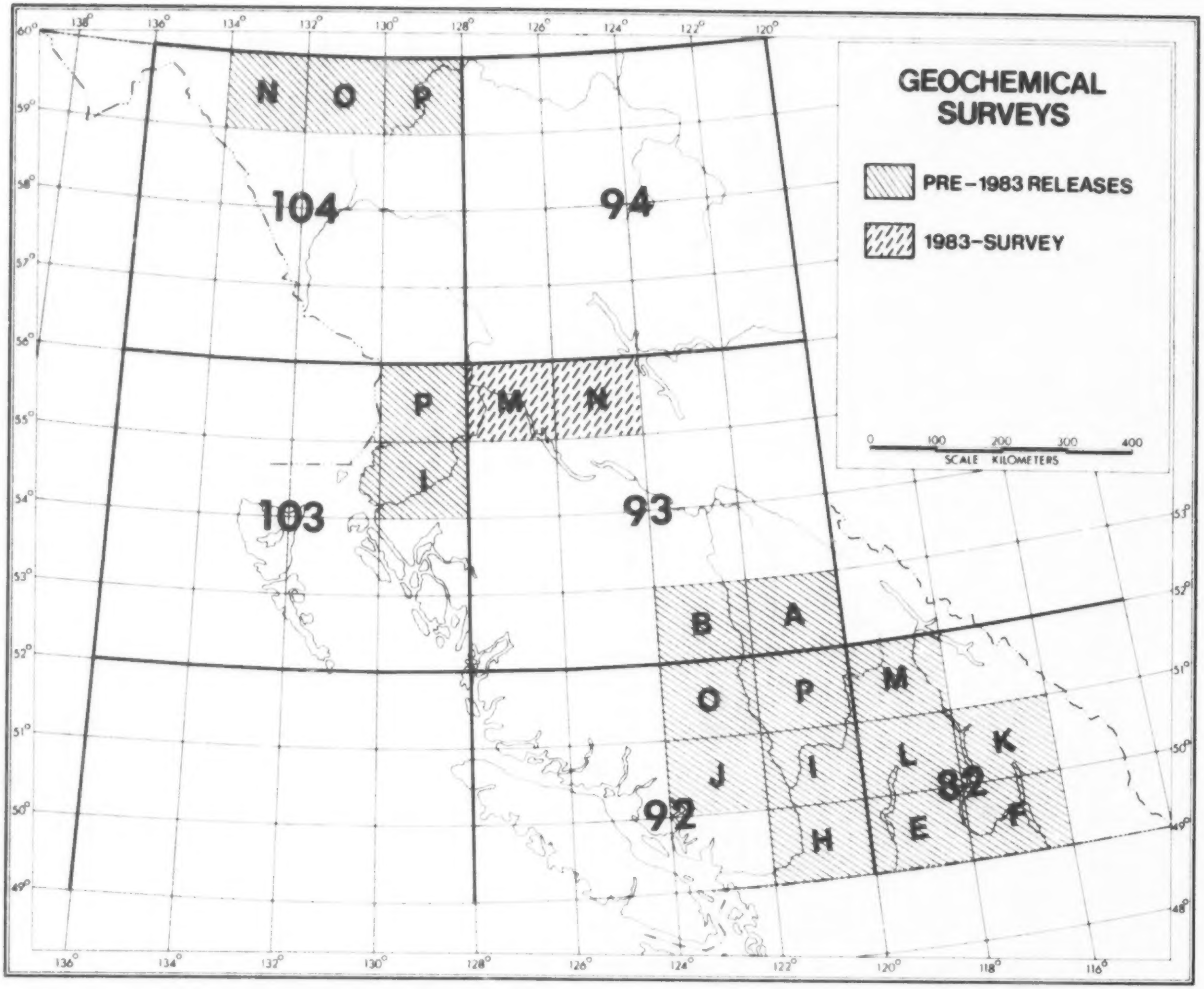


Figure 35. Map showing locations of regional geochemical surveys carried out to date.

# TONSTEINS AND BENTONITES IN NORTHEAST BRITISH COLUMBIA

## (93O, P, I)

By W. E. Kilby

## INTRODUCTION

Tonsteins are presently considered the most reliable coal seam correlation tool available (Stack, *et al.*, 1982). Such ancient volcanic ash bands in coal-bearing and adjacent strata of northeastern British Columbia were examined during the 1983 field season as the preliminary phase of a study documenting these time lines throughout the coalfield. Altered ash bands also were noted and studied by previous workers; Stott (1968), Duff and Gilchrist (1983), and Spears and Duff (in press).

In this paper the terms tonstein and bentonite will be used to broadly group all the types of altered volcanic ash encountered. Tonsteins have a distinct tuffaceous texture and are confined, in this study, to the coal-bearing formations. Bentonites, on the other hand, are generally restricted to marine formations and have the greasy feel and conchoidal fracturing common to bentonite. Montmorillonite-illite and mixed-layer (smectite) group clay minerals are more prominent in the bentonites; kaolinite is the major component of both groups (*see* accompanying table). Generally, a particular band is consistently a tonstein or a bentonite throughout the studied area, but exceptions exist and are very significant. Tonsteins and bentonites examined in this study are the alteration products of volcanic ash. Controversy over the origin of these materials has continued for decades but the last 10 years has seen a general acceptance of their volcanic origin (Stack, *et al.*, 1982). It will be seen that the only plausible explanation for many of the intervals studied here is that they represent volcanic ash. The depositional environment dictates the resulting textures and possibly the mineral assemblages, which are distinctive between the two major groups. Tonsteins-bentonites have been examined in outcrops, trenches, and drill cores. Core obviously provides the best exposure but to obtain an accurate description of the ash characteristics tonsteins within coal seams must often be removed with the coal. For this reason, the search for tonsteins in old core is often frustrated. In contrast, bentonites in Moosebar mudstone were readily identified in core and bands with widths down to several millimetres showed up distinctly. Exploration companies active in the area have been noting these 'tuffaceous' bands for the last several years; company personnel were extremely helpful during the field season allowing examination and sampling of their newly obtained core and pointing out occurrences on their properties.

Initially investigation was concentrated in the Pine Pass area where the majority of exploration activity was occurring. Examination of company trenches and fresh core in this area led to the identification of two readily correlatable tonstein zones in the upper Gething Formation. The latter part of the season's study was completed at the Charlie Lake core facility in Fort St. John examining Gething, Moosebar, and Gates core from Peace River to the Alberta border along the foothills belt. Virtually all ash bands encountered were sampled and are undergoing petrographic, X-ray diffraction, and chemical analyses. Some preliminary results are presented here.

Tonstein-bentonite occurrences are limited to the few sedimentary environments favourable for their preservation. Obviously, any environment with more than a minimal energy level will obliterate ash falls. Thus, tonsteins-bentonites preferentially occur in low-energy marine and coal-swamp settings. Ash falling into marine settings tends to be clean, with only minor bioturbation. Tonsteins preserved in the coal-swamp environment are much more susceptible to organic and detrital contamination. The various degrees and types of contamination provide information for determining the detailed environments at a particular location in the swamp and, potentially, the overall swamp morphology. Some thick (>5 centimetres) bentonites provide recognizable geophysical responses which can be correlated considerable distances (*see* Duff and Gilchrist, Fig. 7), but thin bentonites (3 millimetres to 3 centimetres) are not picked up on a normal suite of logs (detailed gamma might delineate some of these bands but they are seldom used over non-coal intervals). Detailed logs are run over coal intervals, therefore tonsteins can often be recognized. However, contamination or masking by oppositely responding strata usually result in logs that are not distinctive but are recognizable if tonsteins can be seen in the core. Tonsteins-bentonites usually have a high gamma count and a density reading similar to that of mudstone or siltstone. For these reasons, at present, visual inspection is the most reliable means of detecting all the tonsteins-bentonites in a section.

Tonsteins have been grouped into coal and non-coal tonsteins by previous workers in both Europe and British Columbia (Price and Duff, 1969). At this preliminary stage in our study this distinction has not yet been made; it will likely be used when more analytical data is available. Tonsteins, if clean, are easily recognized in core and outcrop. They generally weather medium to light grey in outcrop but may have a rusty appearance (Plate III). In core they tend to be medium grey with sharp contacts. In hand sample tonsteins have a distinctive appearance due to platy kaolinite crystals (Plate IV) and plant fragments often parallel bedding planes. This granular appearance has often resulted in these bands being logged as siltstone or sandstone. They are predominately non-calcareous and can be scratched with a fingernail. The speckled appearance results from development of vermicular kaolinite (Plate V). Stack, *et al.* (1982, page 161) contains an electron micrograph of one of these vermicular structures. Usually, devitrified glass shards or angular crystal fragments are common in these tonsteins (Plate V) confirming their volcanic origin. Mineralogically, tonsteins are kaolin rich; they often have quartz as a secondary constituent (*see* accompanying table). Contamination by organic and detrital material greatly alters the physical appearance of these rocks but detailed examination reveals the distinctive speckled appearance. Organic-rich tonsteins (usually coal tonsteins) are greyish brown in colour; they often contain coal spar.

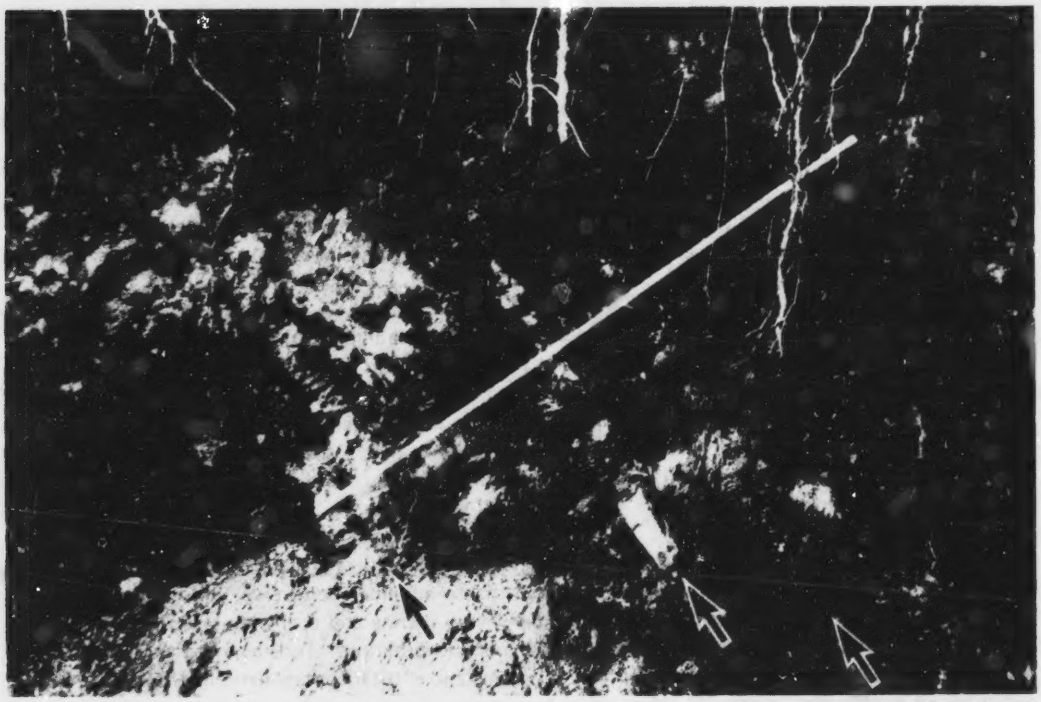


**Plate III.** Fisher Creek Tonstein zone exposed in trench outcrop. Arrows mark the three tonstein bands. The measure is 2 metres.

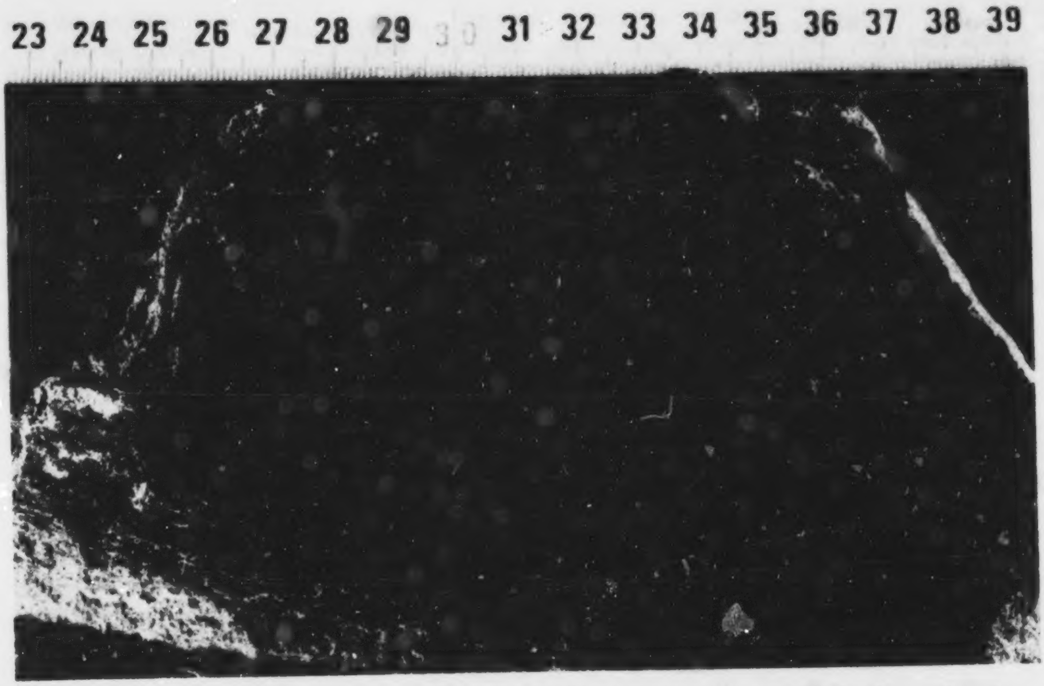


Plate IV. Hand sample of the lowest tonstein in the Fisher Creek sequence. Note carbonaceous fragments and freckled appearance. The freckled appearance is due to vermicular kaolinite.

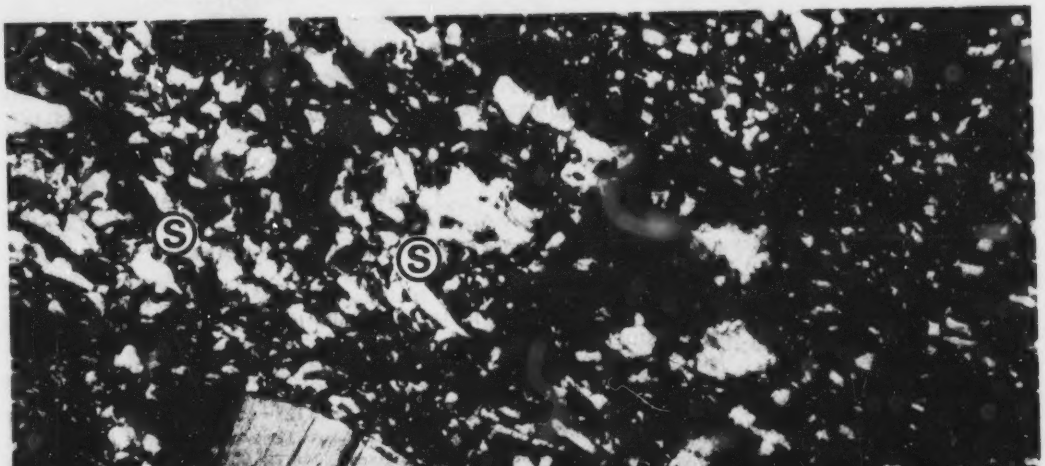


Plate V. Photomicrograph, under-crossed nicols, of tonstein from the Number 1 Seam on the Willow Creek property. This sample may be correlative with the Fisher Creek Tonstein zone. The large 'kaolin worm' is about a millimetre in length. Note devitrified glass shards (S) and a rare form of vermicular kaolinite (K).

| SAMPLE | FORMATION | X–RAY DETERMINATION |
|---|---|---|
| R82– 1 | Moosebar | QUARTZ > KAOLINITE > Fe-rich DOLOMITE |
| 2 | Moosebar | KAOLINITE > QUARTZ > minor amounts of PYRITE, illitic mixed-layer clay, Fe-rich DOLOMITE and APATITE (?) |
| 3 | Moosebar | KAOLINITE > minor amounts of PYRITE, QUARTZ and APATITE |
| 4 | Moosebar | Fe-rich DOLOMITE > KAOLINITE > QUARTZ > minor amounts of PYRITE, CALCITE and APATITE |
| 5 | Moosebar | KAOLINITE with a very small amount of QUARTZ |
| 6 | Gething | KAOLINITE > QUARTZ > a small amount of illitic mixed-layer clay |
| 7 | Moosebar | KAOLINITE > QUARTZ > minor amounts of PYRITE, CALCITE, APATITE ± Fe-rich DOLOMITE |
| 8 | Gething | KAOLINITE > QUARTZ > SIDERITE |
| 9 | Gething | KAOLINITE > QUARTZ > Fe-rich DOLOMITE ≈ PLAGIOCLASE > a minor amount of illitic mixed-layer clay |
| 10 | Gething | KAOLINITE > Fe-rich DOLOMITE > QUARTZ > small amounts of ILLITE, CHLORITE, and Fe-rich MAGNESITE |
| 11 | Moosebar | KAOLINITE ≈ Fe-rich DOLOMITE > trace amounts of QUARTZ and CALCITE |
| 12 | Gething | QUARTZ > illitic mixed-layer clay ≈ DOLOMITE > minor amounts of KAOLINITE and PLAGIOCLASE |
| 13 | Gething | ILLITE > QUARTZ > Fe-rich DOLOMITE > KAOLINITE > trace amounts of MONTMORILLONITE (?) and APATITE (?) |
| 14 | Gething | KAOLINITE > Fe-rich DOLOMITE ≈ QUARTZ > trace amounts of ILLITE, PLAGIOCLASE, and APATITE (?) |
| 15 | Gething | KAOLINITE > QUARTZ > Fe-rich MAGNESITE > illitic mixed-layer clay > PLAGIOCLASE |
| 16 | Gething | KAOLINITE ≈ QUARTZ > Fe-rich MAGNESITE > PLAGIOCLASE ≈ illitic mixed-layer clay |
| 17 | Gething | KAOLINITE ≈ QUARTZ > ILLITE > Fe-rich DOLOMITE |
| 36 | Moosebar | KAOLINITE > ANKERITE/Fe–DOLOMITE > minor QUARTZ > trace APATITE, CALCITE, GORCEIXITE, ILLITE, and CHLORITE ± PYRITE (?) |
| 37 | Moosebar | KAOLINITE > QUARTZ > minor PYRITE > ANKERITE/Fe-DOLOMITE > trace APATITE, ILLITE, K–FELDSPAR ± GORCEIXITE (?) |
| 38 | Moosebar | ANKERITE/Fe–DOLOMITE > KAOLINITE > QUARTZ > CALCITE > trace PYRITE and ILLITE ± APATITE |
| 39 | Moosebar | QUARTZ > KAOLINITE > ANKERITE/Fe-DOLOMITE > PYRITE > trace CALCITE |
| 40 | Moosebar | QUARTZ > KAOLINITE > ANKERITE/Fe-DOLOMITE > PYRITE > minor ILLITE > CALCITE |
| R83– 81 | Gething | KAOLINITE > ILLITE–MONTMORMILLONITE (mixed-layer clay) > minor QUARTZ PLAGIOCLASE |
| 82 | Gething | QUARTZ ≈ KAOLINITE > minor ILLITE–MONTMORILLONITE (mixed-layer clay) PLAGIOCLASE and DOLOMITE |
| 83 | Gething | KAOLINITE > QUARTZ > PLAGIOCLASE > Fe-rich DOLOMITE > trace ILLITE–MONTMORILLONITE |
| 87 | Gething | KAOLINITE > QUARTZ > trace ILLITE–MONTMORILLONITE (mixed-layer clay) |
| 90 | Gething | QUARTZ > ANKERITE > ILLITE–MONTMORILLONITE > KAOLINITE ≈ CALCITE > SIDERITE |
| 151 | Moosebar | MONTMORILLONITE ≈ KAOLINITE > minor QUARTZ > trace SIDERITE ± ALLOPHANE |
| 152 | Moosebar | CALCITE > ANKERITE > SIDERITE > QUARTZ ≈ KAOLINITE > trace ILLITE |
| 156 | Moosebar | KAOLINITE ≈ MONTMORILLONITE > QUARTZ > SIDERITE ± ALLOPHANE |
| 177 | Moosebar | Fe-rich DOLOMITE > KAOLINITE > trace QUARTZ and PYRITE ± GORCEIXITE |
| 178 | Moosebar | Fe-rich DOLOMITE ≈ KAOLINITE > minor QUARTZ, PYRITE, GORCEIXITE, ± APATITE |
| 179 | Moosebar | KAOLINITE > Fe-rich DOLOMITE > QUARTZ > minor PYRITE |
| 182 | Gething | KAOLINITE > QUARTZ > trace CHLORITE, APATITE (?) ± DOLOMITE |
| 183 | Gething | KAOLINITE > QUARTZ |
| 184 | Gething | KAOLINITE > QUARTZ > Fe–DOLOMITE > trace APATITE |
| 185 | Gething | KAOLINITE > QUARTZ > Fe–DOLOMITE > ILLITE > trace APATITE (?) |

Bentonites are even more readily recognized in core and outcrop than tonsteins. The material tends to be light grey to greenish grey, consists of clay size material, and has a conchoidal fracture. When weathered at surface the band usually develops the classic 'popcorn' texture common to these swelling clays. Depending upon outcrop conditions the band may become completely softened. Due to swelling and light colour, bands as thin as 3 millimetres can be apparent on a clear outcrop surface. In hand sample this material is greasy when wet and breaks into 'poker chip' or cuspate fragments. Although usually non-calcareous, some bands have been subjected to late carbonate replacement. Where found in the marine Moosebar Formation the bentonites often display well-preserved bioturbation. At one location a bentonite in the glauconite portion of the 'Bluesky' is slightly glauconitic. In marine settings the bentonites are usually free of contamination other than that introduced by bioturbation; occasionally they are interlaminated with the surrounding mudstones. Kaolinite predominates in the bentonites, but montmorillonite-illite clays are also important (*see* accompanying table).

At present the only means of correlating various tonsteins-bentonites are their approximate stratigraphic position, thickness, and relationship with one another. Petrographic and chemical correlation techniques will be applied as analyses become available.

The 'Fisher Creek Tonstein' zone was initially recognized in exploration trenches on Crows Nest Resourses Ltd.'s Pine Pass property. Early correlations were based on the presence of a thin 1 to 2-centimetre coaly band near the middle of a thick (20-centimetre) tonstein. Better exposures revealed several thinner tonsteins in the overlying few metres of strata (Plate III). With familiarity, this series of tonsteins became recognizable in core and outcrop. Figure 36 contains a series of sections through the Fisher Creek Tonstein zone. Note the variations in inter-tonstein lithology and thicknesses. This zone is located approximately 45 metres below the Bluesky unit (Moosebar-Gething boundary) (Fig. 38a and b); at present it has only been recognized in the Pine Pass area (Fig. 37) due in large part to a lack of detailed investigation outside this area.

The 'Number 2 Tonstein' is located about 20 metres stratigraphically below the Fisher Creek Tonstein zone or about 65 metres below the Bluesky (Fig. 38a and b). It is usually clean and consists either of one thick band (20 centimetres) or a large band and a series of thinner tonsteins all within a short stratigraphic interval. This tonstein is present in the middle of the Number 2 Seam on David Mineral Ltd.'s Willow Creek property. So far, it has been recognized mainly in the same sections as the Fisher Creek Tonstein zone.

From Peace River to Onion Creek bentonites were located in core in the lower portion of the Moosebar mudstone. Two prominent bentonite bands ('Twin Bentonites') were noted by Duff and Gilchrist (1983) and tentatively correlated over much the same area as this study. These two bentonites are readily seen on geophysical logs and are obvious in outcrops of the lower Moosebar. In the Bullmoose and Mount Spieker areas they are located about 4 metres above the Bluesky; the bands, which are about 10 centimetres thick, are 3 to 5 metres apart. In the Monkman area the Twin Bentonites are 30 metres above the Bluesky and 3 metres apart. In the Peace River area they are about 140 metres above the top of the Gething but this interval contains the Moosebar Lower Silty Member which is not present south of Sukunka River. In addition to these two prominent bands (shown on Duff and Gilchrist, Fig. 7), a zone of several thinner bentonites is usually present a short distance below the Twin Bentonite bands (Fig. 38a and b). Correlation of these thinner bands has not yet been accomplished over any significant distance but they have helped to solve one stratigraphic anomaly and have potential for documenting the relationship between the Moosebar Mudstone Member and the Moosebar Lower Silty Member. A recent visit to the Grande Cache area of Alberta revealed at least four thin bentonite bands in the lower Moosebar mudstones of that area.

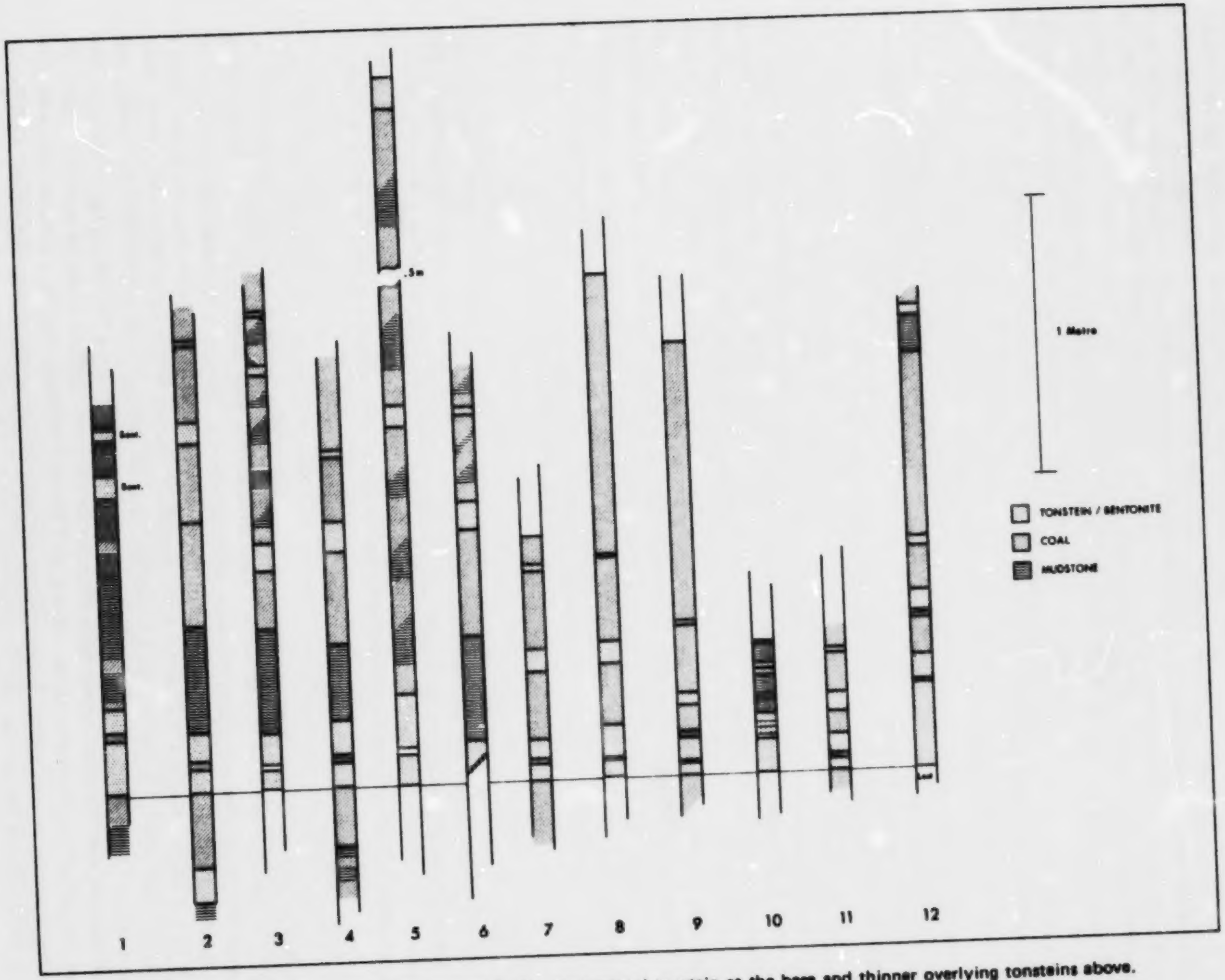


Figure 36. Fisher Creek Tonstein zone with the thick-parted tonstein at the base and thinner overlying tonsteins above. The exaggerated thickness in section 5 is due to structural thickening along numerous closely spaced shears.

Tonsteins are also present in the Gates Formation, but very little effort has been directed to these strata yet. Crows Nest Resources drilled through a clean (5-centimetre) tonstein near Mount Secus; in equivalent strata in the Grande Cache area a tonstein was found in and around the top of the Number 4 Seam. Carmichael (1983) noted bentonites in the Gates and Moosebar Formations south of the area of this study. The next phase of this study will include an investigation of the Gates strata for these time lines.

The availability of precise and recognizable time lines in the stratigraphic column enable a wide range of studies to be undertaken and problems solved. During the 1983 field season tonsteins-bentonties were used to solve several structural and stratigraphic problems and provided several hints about the paleogeography of Cretaceous coal-bearing and adjacent strata.

Mesoscopic structures within and around coal seams are often complex and difficult to map because distinct marker horizons are lacking and lateral lithologic variations are rapid. A large trench on Crows Nest Resources' property exposed a disturbed sequence of coal measures on the east limb of the Fisher Creek Syncline. Within this trench the Fisher Creek Tonstein sequence was repeated five times, each time with different orientations. This fortunate exposure (Fig. 39) enabled the detailed structural style in that locality to be understood and sedimentary variations over short distances to be examined (Fig. 36, columns 2 to 6).

During investigation of the Fisher Creek Tonstein one location was encountered where two of the upper bands were found to be bentonite or bentonitic (Fig. 36, column 1). Tonsteins are believed to form under acidic or possibly laterizing conditions in or adjacent to coal swamps. Bentonites apparently result when ash falls into a more normal or alkaline environment. Figure 37 illustrates the positions of some Fisher Creek Tonstein sections, Figure 36 shows the detailed lithology surrounding these bands, and the accompanying table contains a mineralogical description of some of these samples. The significance of this tonstein to bentonite transition is that some major facies boundary has been crossed. The bentonites formed outside the coal swamp facies, possibly in some abandoned channel, maybe even in a marine environment. At the very least the change marks the position of the edge of the swamp at the time of these ash falls.

In Duff and Gilchrist (1983, Fig. 7), drill hole Mount Spieker MS–1 contains an anomalous unit, the Lower Silty Member, at the bottom of the Moosebar Formation. This log was used while examining several outcrop sections of the Gething and lower Moosebar in the area of the hole. It was obvious that something was amiss because the two distinctive bentonite gamma kicks at 1,341 feet and 1,349 feet in conjunction with the common Gething-Moosebar pick at 1,386 feet matched outcrop sections exactly. Examination of the core stored at Charlie Lake revealed that this interval contains a thrust fault which duplicates the formation contact and several of the bentonites (Fig. 40). During relocation of the core to Charlie Lake several years ago, the core was reboxed; the interval above 1,350 feet is now completely shattered in typical mudstone fashion and no trace of the upper bentonite at 1,341 feet could be seen. This disturbed core and missing bentonite may have resulted in misinterpretation of this interval. In this case a combination of bentonites and distinctive stratigraphic markers were used to solve a 'sedimentological' problem and brought this section back in line with its surroundings.

The Moosebar transgression and associated Bluesky equivalent unit in the foothills belt may be effectively bracketted by tonsteins and bentonite horizons. At present regional correlations have not been made but on a local scale some observations will be made about this interval in an accompanying paper (this volume) which discusses some of the features of the Bluesky unit and surrounding strata.

This project is in its infancy but local and regional correlations now appear attainable. On a local (property) scale tonsteins-bentonites are now being used for borehole and outcrop correlations. Regionally, these ash bands provide an unparalleled opportunity to understand the coal swamps, their lateral extent, vegetation distribution, and the relative accumulation rates of vegetation and sediments within their bounds.

The objective of this study is to document the ash bands (tonstein-bentonite) in the coal-bearing and adjacent strata of the Northeastern British Columbia Coalfield. Analyses will be undertaken to find out if various tonstein-bentonite zones have unique chemical attributes which can be used to chemically fingerprint particular zones and fix their positions within the section. Chemical correlations have been promising in other studies (Amajor and Lerbekmo, 1980; Glass, 1981); chemical analysis of the collected samples is presently underway.

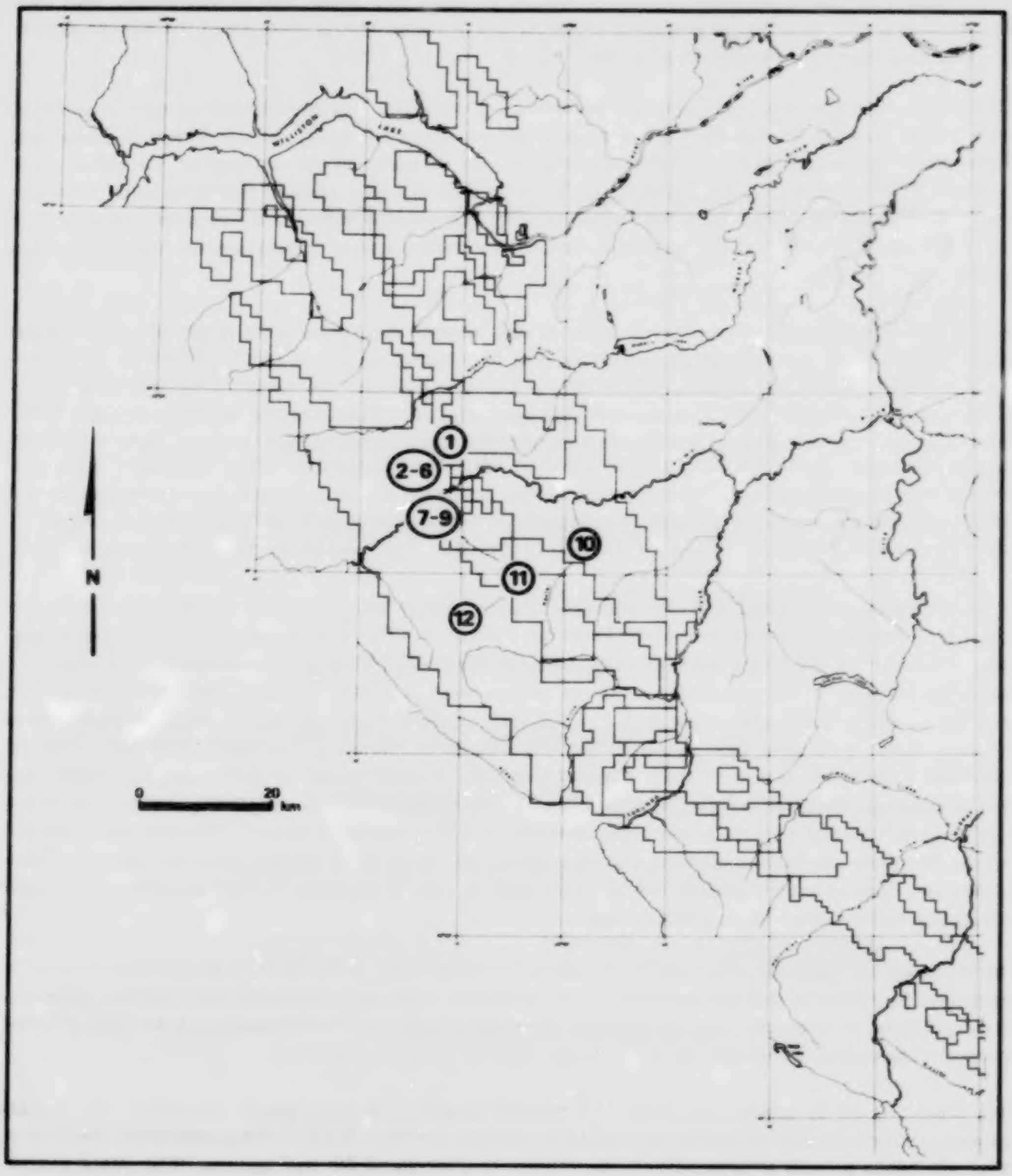


Figure 37. Approximate locations of Fisher Creek tonstein sections (due to the confidentiality of much of the data only one hole is accurately located – Pine Pass 75–10).

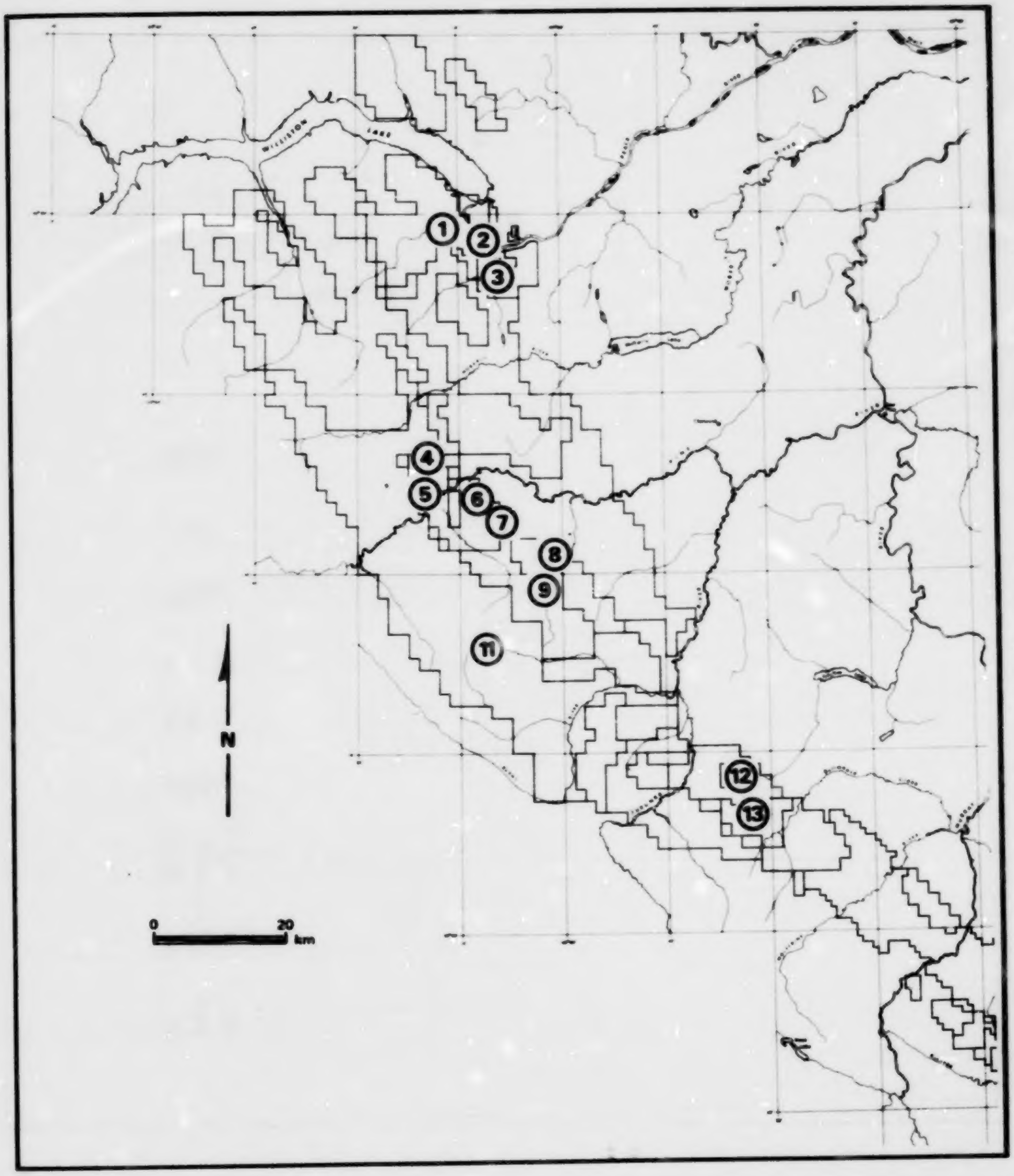
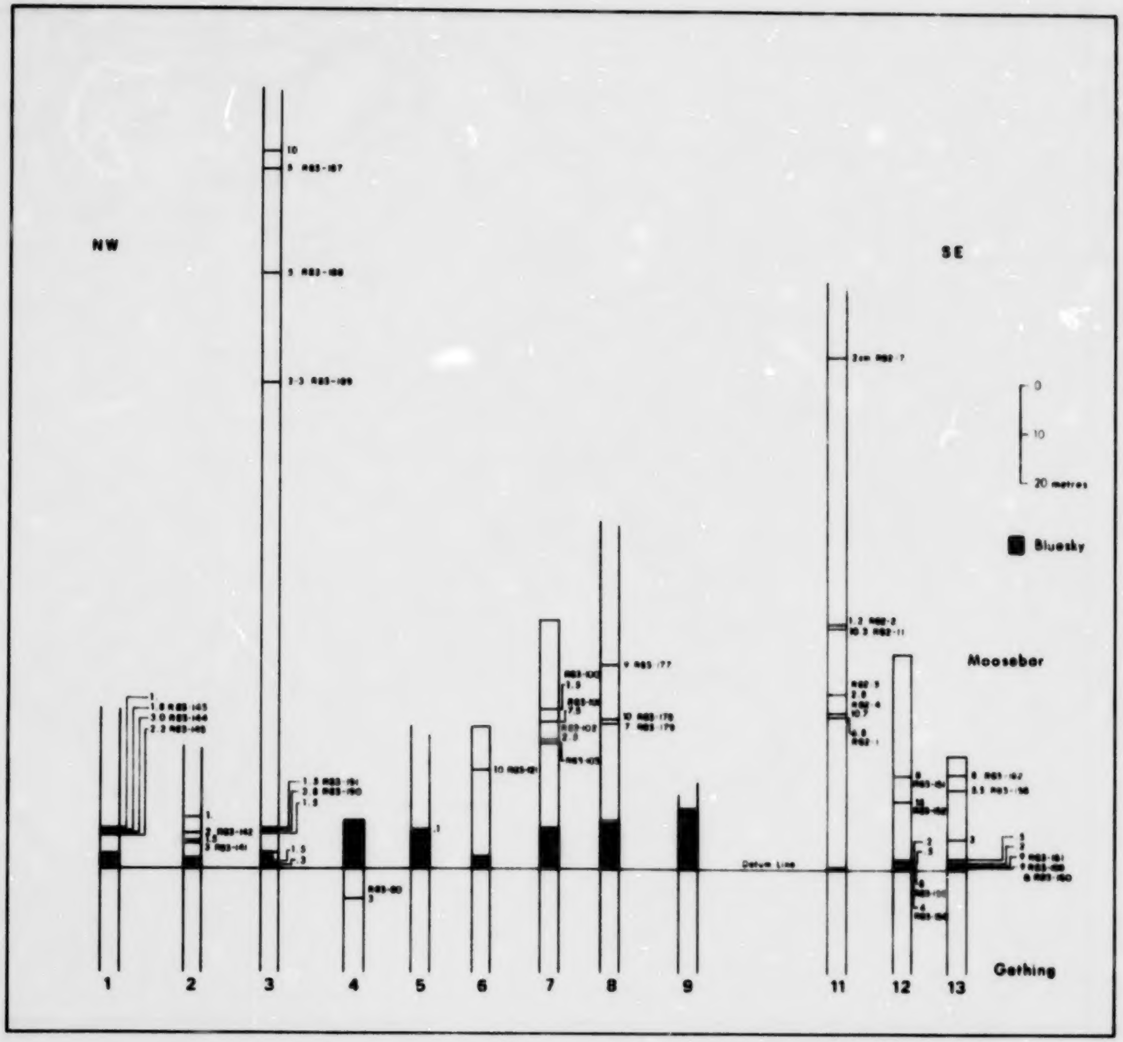


Figure 38a. Exact or approximate locations of drill holes used on Figure 37 (depending on their confidentiality).


NW
SE
10
5 R83-187
5 R83-188
2.3 R83-189
2cm R82-7
0
10
20 metres
Bluesky
1.2 R82-2
10.3 R82-11
Moosebar
9 R83-177
10 R83-178
7 R83-179
10 R83-121
1.8 R83-165
3.0 R83-164
2.2 R83-163
1.3 R83-191
3.8 R83-190
6 R83-157
3.5 R83-156
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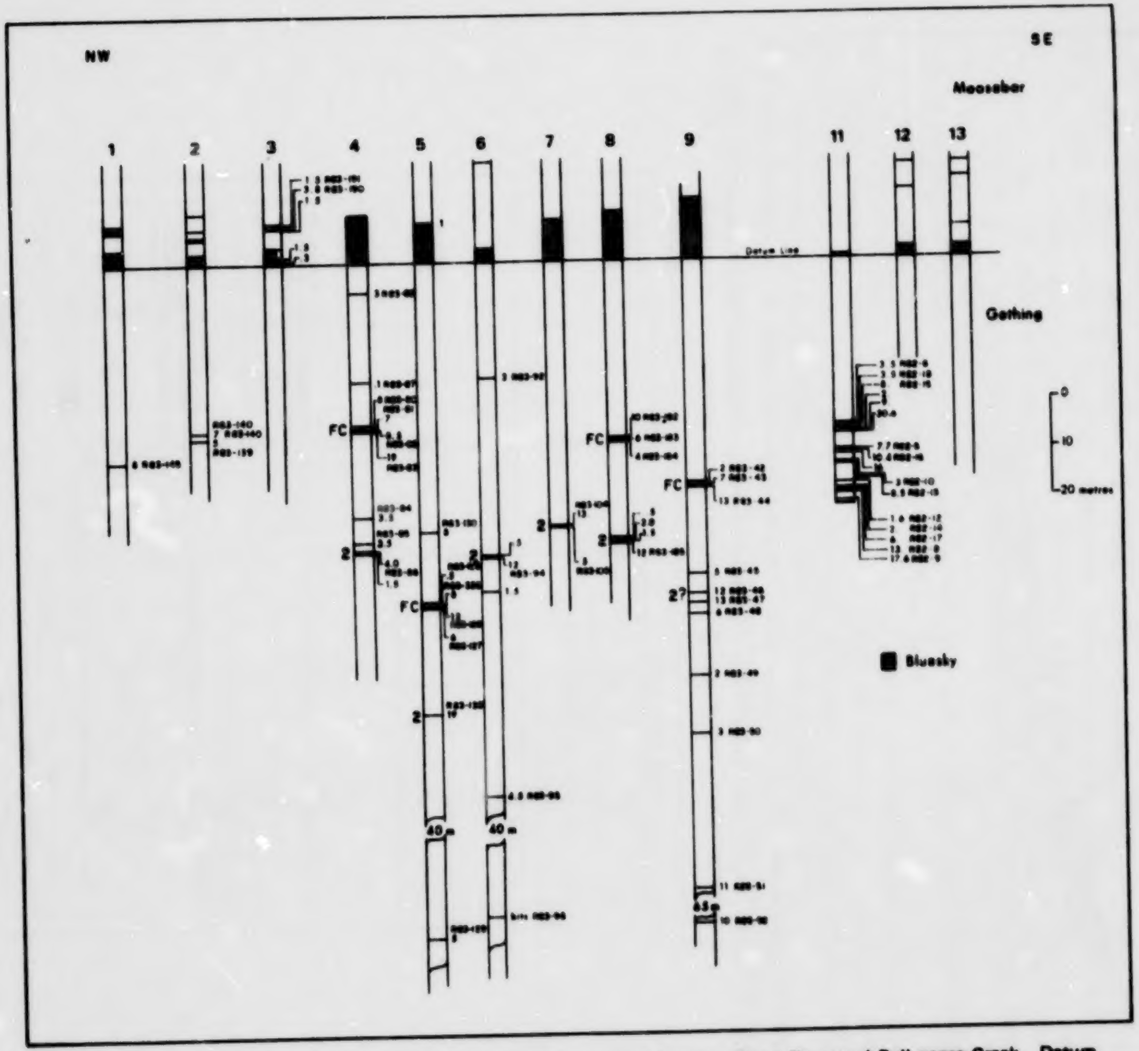

Figure 38b. Tonstein/bentonite locations in some borehole sections between Peace River and Bullmoose Creek. Datum is the base of the Bluesky unit. Ash bands are shown as solid lines with their thicknesses given in cnetimetres. Sample numbers are also given for all sampled bands.

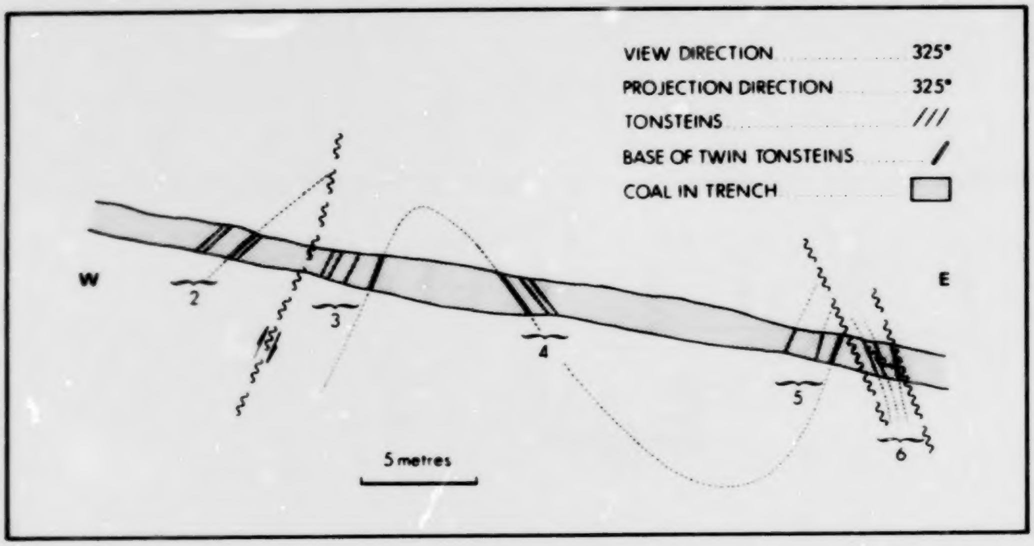

Figure 39. Section view of trench exposure with the deformed sequence containing the Twin Tonsteins. The numbers of the bracketted zones correspond with the detailed sections on Figure 36.

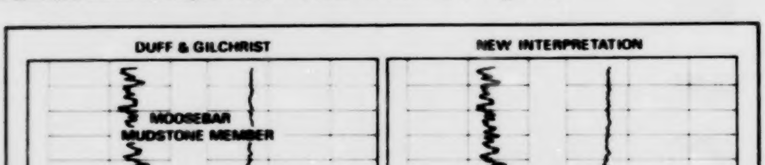

Figure 40. A structural explanation of a stratigraphic anomaly – fault movement resulted in 47 feet (14 metres) of repeated section. The Gething upper contact is also moved to the base of the Bluesky, above the first occurrence of coal spar and stringers.

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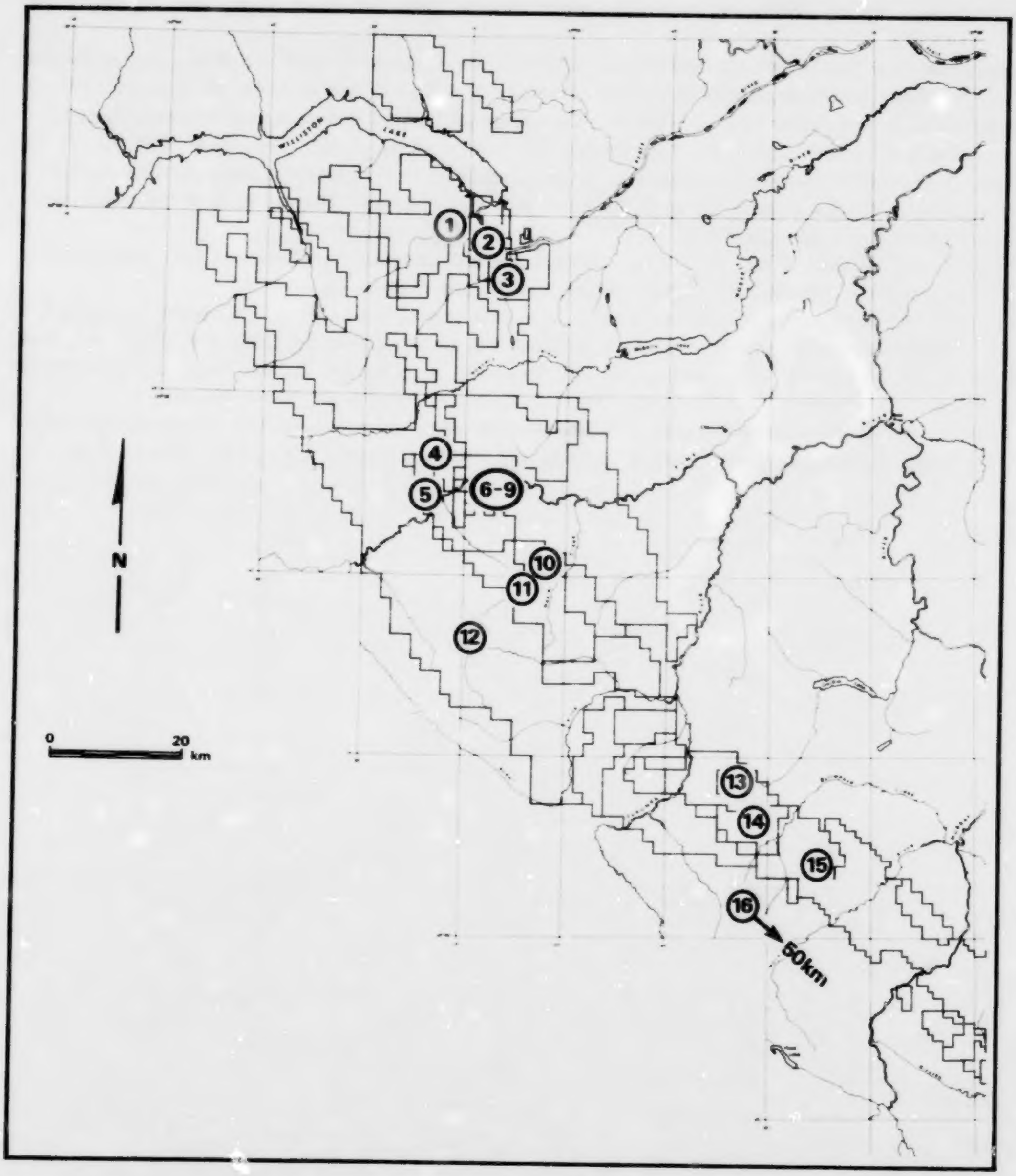

Figure 41. Location map of sections shown on Figure 42 (locations are exact or approximate, depending on confidentiality).

# THE CHARACTER OF THE BLUESKY FORMATION IN THE FOOTHILLS OF NORTHEASTERN BRITISH COLUMBIA

## (93O, P, I)

By W. E. Kilby

The Bluesky Formation has been extensively studied and mapped in the subsurface of northeastern British Columbia and Alberta (Alberta Study Group, 1954; Pugh, 1960; Karst, 1981; and White, 1982). There it reaches a thickness of 25 metres and is an oil and gas producer. In the adjacent foothills equivalent strata are encountered in the course of coal exploration. The unit is situated between the marine Moosebar and the coal-bearing Gething Formations; it is important as a marker horizon over much of the Northeastern British Columbia Coalfield. The unit may also be important in controlling the pyrite content in some underlying Gething coals. Widely spaced sections show that the Bluesky varies considerably in thickness and lithological composition (Figs. 41 and 42). Taken in conjunction with tonstein/bentonite 'time lines' it becomes apparent that the erosional base of the unit is regionally irregular. Previous work showed that what has traditionally been referred to as Bluesky equivalent strata north and south of the Sukunka River are at two different stratigraphic positions (Duff and Gilchrist, 1982). In this paper these two stratigraphically different occurrences will be informally referred to as Bluesky-N and Bluesky-S. Bluesky-N is found north of the Sukunka River and is stratigraphically below Bluesky-S.

In beds known as Bluesky, as in the coal-bearing Gething and Gates Formations, there appears to be a major change in character between the Sukunka and Wolverine Rivers. North of this area the Gates is dominantly marine and lacks major coal seams; the Gething is the major coal-bearing sequence. To the south the Gates contains economically important seams; the Gething is less important. Throughout Cretaceous time the Peace River Arch affected sedimentation patterns in this area (Stott, 1975; Stelk, 1975).

In the Sukunka-Wolverine area what is known as the Bluesky-S is usually about 1 metre thick, is glauconitic throughout, and may contain some sand or floating pebbles (Fig. 42, stratigraphic columns 12 to 14). Two prominent bentonite bands (Twin Bentonites) lie 4 to 6 metres above the Bluesky-S horizon in this area. To the north rocks equivalent to the Bluesky-N can be broken into three units: basal conglomerate, middle silty mudstone, and upper glauconitic unit (Fig. 42, stratigraphic columns 2 to 11).

The basal conglomeratic unit can vary from coarse sand to cobble-sized material; thicknesses vary from negligible to more than 10 metres. Angular chert pebbles less than 1 centimetre in diameter are common but occasionally well-rounded cobbles are up to 4 to 5 centimetres in diameter. The middle unit consists of pyritic, bioturbated, and turbiditic silty mudstone; it varies from tens of centimetres to several metres in thickness. The turbidites are thin (3 to 5 centimetres) and probably storm generated. This middle unit commonly displays a coarsening upward trace on geophysical logs. There are varying degrees of bioturbation, usually consisting of small (2 to 3-millimetre) black burrows that are spherical in cross section; they may represent *chondrites* or a similar type of trace fossil. Pyrite is usually present in the form of nodules up to 1 centimetre in length. The upper glauconitic unit can vary in thickness from several cenimetres to several metres. With the exception of number 12, glauconite occurs in all sections examined. Number 12 is the most westerly location examined (Fig. 42). Glauconite content varies from a few scattered grains to about 80 per cent where it forms glauconite sand. Glauconite identification referenced is based on hand sample examination and is not yet verified by thin section or X-ray work. These three units in the Bluesky-N are believed to represent a two-phase transgression.

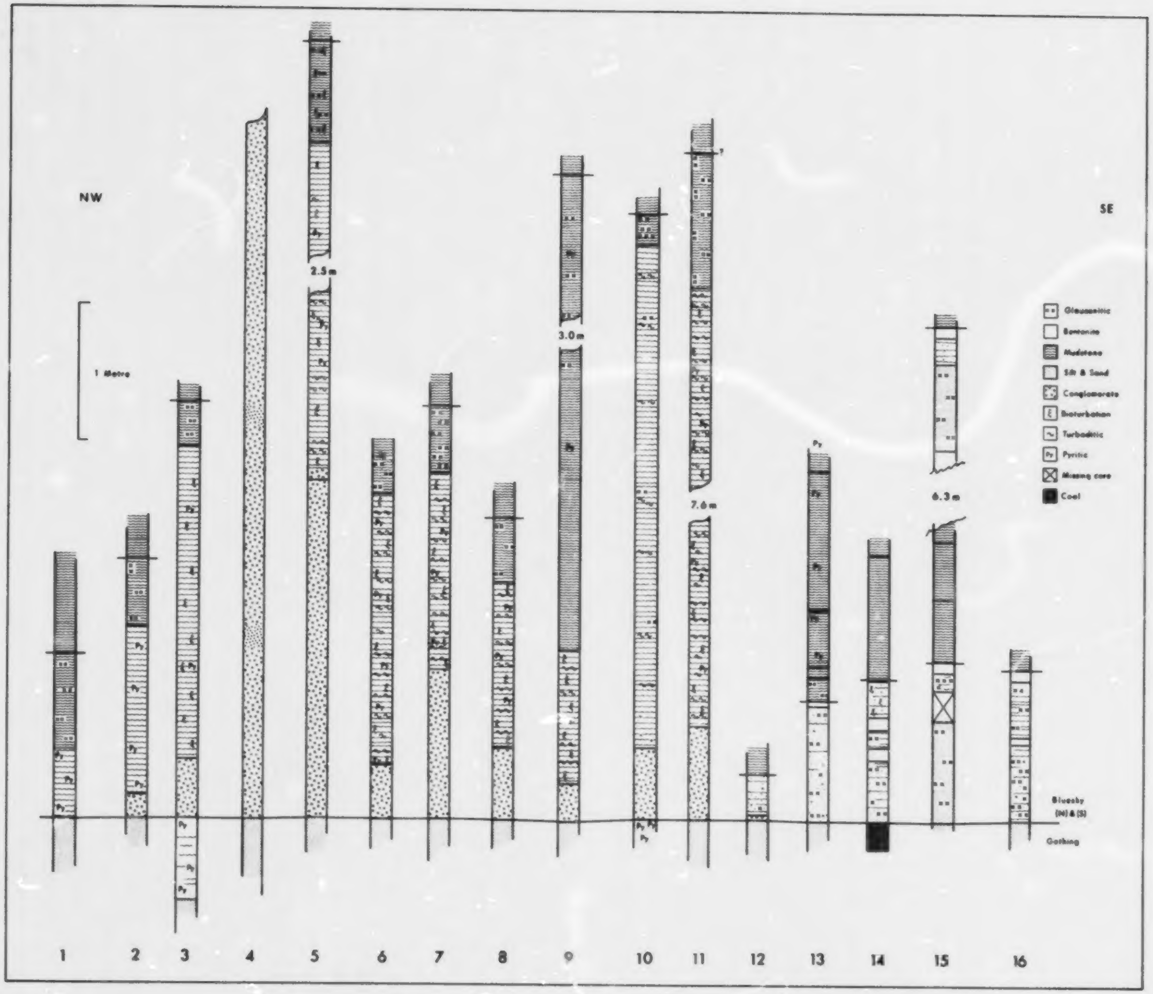

Figure 42. Detailed sections of the Bluesky equivalent strata from coal exploration drill cores.

Variable Bluesky-N thicknesses and thickness changes in the Gething Formation between the Fisher Creek Tonstein zone and the Bluesky-N suggest an irregular and possibly channelled erosional surface (Kilby, this volume, Fig. 37).

In areas where coals are present at the top of the Gething Formation, the thickness of the Bluesky was thought to be related to the quality of the coal. When peat swamps are subjected to marine influence, they usually show an increase in pyrite content. It was thought that when the Bluesky was less than a critical thickness the sulphur content of the underlying coal seam became greater than 1 per cent (Gilchrist, 1978). Shielding of coal seams from marine influence is well known and documented in other areas (Stack, 1982 and Horne, 1978). However, in this case the Bluesky itself is marine, therefore the sulphur content of the underlying seams should be high. Perhaps the strata between the seam and the Moosebar are not all marine perhaps non-marine Gething sediments were deposited over the peat swamp prior to the marine incursion. This type of occurrence is well documented in the eastern United States (Horne, 1978). Often medium to coarse sands lie between the Bluesky and the uppermost coal. For convenience the top of the Gething has generally been positioned at the top of the uppermost coal seam; in reality some of the overlying sands may also be non-marine Gething. It appears that the sulphur shielding is actually dependent on the thickness of the coal-to-Bluesky interval not on the thickness of the Bluesky. A more detailed investigation of stratigraphic relationships and the type and distribution of pyrite in the seams is required to solve this problem.

Glauconite can form in a wide variety of low-energy environments, both marine and lacustrine. It is often associated with transgressions, which is true in the case of the Bluesky; it marks the southerly transgression of the Moosebar-Clearwater Sea over the coal-bearing Gething-Gladstone Formations. The glauconitic portion of the Bluesky-N is in gradational contact with the lowermost part of the Moosebar Lower Silty Member; the glauconite occurs in a mudstone matrix. This setting is consistent with authigenic formation of glauconite (McRae, 1972). Glauconite formation is considered possible only in non-turbulent waters, that is, below wave base (30 to 50 metres).

Duff and Gilchrist (1982) showed that what has traditionally been referred to as Bluesky equivalent strata over the length of the coalfield occurs in two different stratigraphic intervals. North of Sukunka River the distinctive three-unit Bluesky-N lies between the Moosebar Lower Silty Member and the Gething Formation. The Bluesky-S lies between the Moosebar Mudstone Member and the Gething Formation; which of these units is actually correlative to the type Bluesky of the plains is unclear at present. The positions of the Twin Bentonites over both these glauconitic transgressive deposits over the length of the coalfield support the interpretation that they occur at two stratigraphic levels. Detailed examination of these bentonites and several others lower in the section may help in pin-pointing the stratigraphic position of the Bluesky-S in the Peace River area.

A staggered transgressive history for the Moosebar-Clearwater Sea is implied by the interpretation that there are two 'Bluesky Formations'. The initial transgression of this boreal sea formed the conglomerate unit of Bluesky-N. A minor regression occurred during deposition of the middle unit, witnessed by its coarsening upward character. Then a major transgression occurred in the northern area which resulted in flooding southward to the approximate position of the Peace River Arch. The resultant deep, tranquil water favoured glauconite formation at the top of the Bluesky-N sequence. Following this inundation a slow regression was occurring, resulting in the deposition of the coarsening-up Moosebar Lower Silty Member in the north. During this period, in the area of the Sukunka River, deltas and coal swamps were migrating northward over the lowest Lower Silty Member. Following this regression a major transgression occurred flooding virtually all of the Northeastern British Columbia Coalfield and resulting in the formation of the Bluesky-S unit south of the Sukunka River; mudstone deposition continued to the north. A short while after this incursion the Twin Bentonites were deposited. At present the bentonites can be traced about 170 kilometres in a northwest-southeast direction and provide an approximate time marker of this last major Moosebar transgression. Carmichael (1983) tentatively correlated these bentonites with similar rocks in the Torrens Member of the Gates Formation in the Dumb Goat Mountain area, suggesting the major regression had already started at the time of their deposition. He also points out that what has been referred to as the Torrens Member north of the Wapiti River is actually a higher stratigraphic unit, his Sheriff Member. Obviously the history of the Moosebar-Gething contact (Bluesky) has yet to be fully understood.

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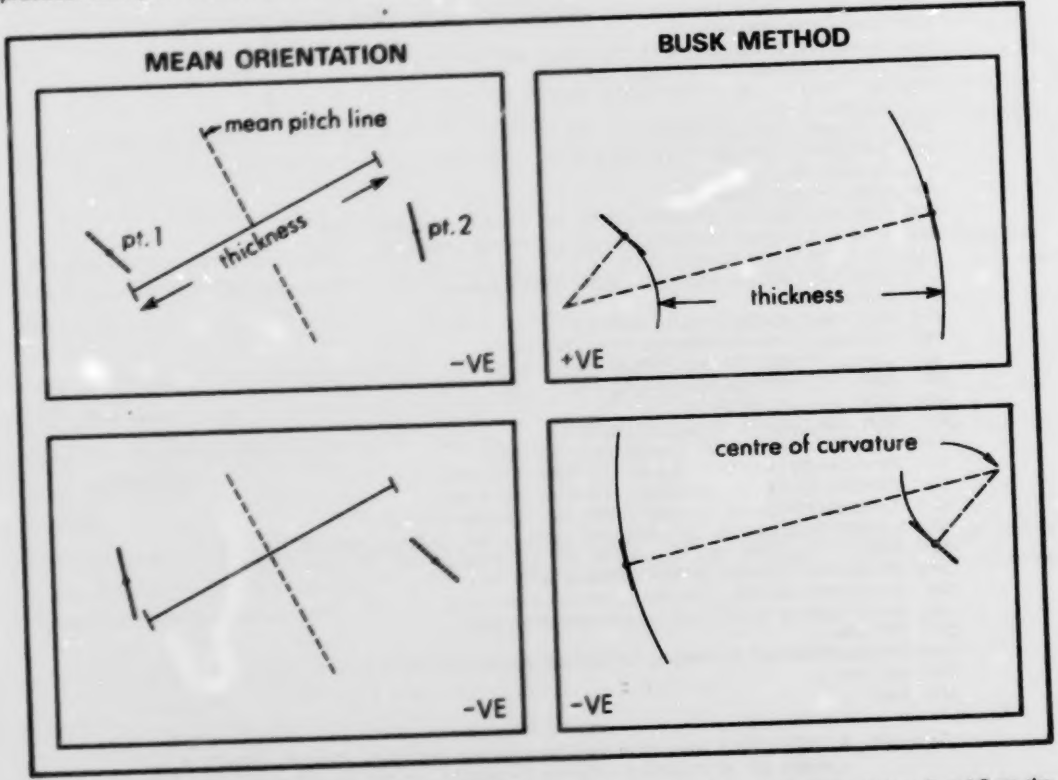
# A USEFUL MICRO–COMPUTER PROGRAM

By W. E. Kilby

The last few years have seen a proliferation of portable and hand-held micro-computers (electronic notebooks). Recently, exploration companies have been making increased use of these machines while in the field. Unfortunately, few programs are widely available to handle geology-specific tasks on these versatile tools.

The program described here, THICK calculates the stratigraphic thickness between two points with similar or differing bedding orientations. The program given here (Fig. 43) is written in Microsoft BASIC and will run with little or no modification on most of the popular micro-computers. The small memory requirements (3K bytes) allow the program to run on most all hand-held computers as well as inexpensive computers. Positional and orientation data for both points are entered as x, y, z coordinates and dip direction and dip angles, respectively. The program contains useful routines of interest in structural geology. Charlesworth and Kilby (1980) contains a detailed explanation of the numerical techniques as well as a practical example. Busk (1929) illustrates the equivalent graphical procedures.



MEAN ORIENTATION

BUSK METHOD

Figure 43. Examples of the signing of the thickness results from the two calculation techniques. Points 1 and 2 are the pitch lines projected onto the plane of profile.

```
1   REM************************* THICK ***********************
2   REM***                    W.E.KILBY                    ***
3   REM*******************************************************
100 PI=3.14159/180:PK=1.5708
109 REM ARCCOSINE
110 DEF FNAC(Q)=-ATN(Q/SQR(-Q*Q+1))+PK
119 REM ENTER POSITIONAL AND ORIENTATION DATA
120 INPUT"ENTER X,Y,Z COORDS OF O/C 1";X1,Y1,Z1
130 INPUT"ENTER DIP-DIR. AND DIP OF O/C 1";D1,P1
140 INPUT"ENTER X,Y,Z COORDS OF O/C 2";X2,Y2,Z2
150 INPUT"ENTER DIP-DIR. AND DIP OF O/C 2";D2,P2
160 P=(90-P1)*PI:T=(D1+180)*PI
170 GOSUB 580
180 L1=L:M1=M:N1=N
188 REM TEST IF ORIENTATIONS DIFFERENT, IF SAME CALCULATE THICKNESS
189 REM BY MEAN METHOD.
190 IF (D1=D2)AND(P1=P2)THEN L3=L1:M3=M1:N3=N1:GOTO 260
200 P=(90-P2)*PI:T=(D2+180)*PI
210 GOSUB 580
220 L2=L:M2=M:N2=N
229 REM CALCULATE MEAN ORIENTATION
230 L3=COS((FNAC(L1)+FNAC(L2))/2)
240 M3=COS((FNAC(M1)+FNAC(M2))/2)
250 N3=COS((FNAC(N1)+FNAC(N2))/2)
260 TH=(X2-X1)*L3+(Y2-Y1)*M3+(Z2-Z1)*N3
270 PRINT"THICKNESS BY MEAN ORIENTATION METHOD IS =  **";
279 REM CALCULATE DIRECTION COSINES
280 PRINT TH;"**":IF (D1=D2) AND (P1=P2) THEN 600
290 L3=L1:M3=M1:N3=N1:L4=L2:M4=M2:N4=N2
300 GOSUB 540
310 IF DE=0 THEN P=0:T=T+PK:GOSUB 580:LB=L:MB=M:NB=N:GOTO 330
320 LB=LL:MB=MM:NB=NN
330 NT=ATN(LB/MB):NP=ATN(NB/SQR(-NB*NB+1))
340 IF(LB<0)AND(MB<0)THEN 370
350 IF MB>0 THEN NT=NT:GOTO 370
360 NT=PK*4+NT
370 T=NT+PK:P=0:GOSUB 580
380 LH=L:MH=M:NH=N:T=NT:P=PK-NP
390 GOSUB 580
400 LV=L:MV=M:NV=N
409 REM CALCULATE COORDINATES OF POINTS ON PROFILE
410 X3=LH*X1+MH*Y1+NH*Z1:Y3=LV*X1+MV*Y1+NV*Z1
420 X4=LH*X2+MH*Y2+NH*Z2:Y4=LV*X2+MV*Y2+NV*Z2
430 L3=L1:M3=M1:N3=N1:L4=LB:M4=MB:N4=NB
440 GOSUB 540
449 REM CALCULATE PITCH ANGLES
450 AN=LL*LH+MM*MH+NN*NH:A1=FNAC(AN)
460 L3=L2:M3=M2:N3=N2:GOSUB 540
470 AN=LL*LH+MM*MH+NN*NH:A2=FNAC(AN)
480 X5=X3-X4:Y5=Y3-Y4
489 REM CALCULATE BUSK THICKNESS
490 SU=COS(A1)*SIN(A2)-COS(A2)*SIN(A1)
500 PP=SIN(A1)*(Y5*SIN(A2)-X5*COS(A2))/SU
510 QQ=COS(A1)*(Y5*SIN(A2)-X5*COS(A2))/SU
520 TH=SQR(PP^2+QQ^2)-SQR((PP-X5)^2+(QQ-Y5)^2)
530 PRINT"THICKNESS BY BUSK METHOD = ** ";TH;" **":GOTO 600
539 REM CALCULATE ORIENTATION OF INTERSECTION OF TWO PLANES
540 DE=L3*M4-L4*M3:IF DE=0 THEN 570
550 D=(M3*N4-M4*N3)/DE:E=(L4*N3-L3*N4)/DE
560 NN=1/SQR(D^2+E^2+1):LL=D*NN:MM=E*NN
570 RETURN
580 L=SIN(T)*COS(P):M=COS(T)*COS(P):N=-SIN(P)
590 RETURN
600 END
```

Figure 44. A MICROSOFT basic version of the thickness calculation program. Only lines with numbers evenly divisible by 10 need be entered; the rest are comment lines. In its present form the program can be easily adapted to take advantage of machine-specific features.

Two methods of thickness calculation are employed in the program: the mean orientation, and the Busk techniques. If identical orientations are present at both positions this value is used in the mean orientation technique and the Busk method is neglected. When varying orientations are entered, the mean orientation between those entered is used in the mean technique while the two different orientations are used for calculating the Busk thickness. Results from the two techniques are given so the user may compare the results and explain discrepancies, if any. The results are signed, indicating relative positions between data points. In the case of the mean method a negative value indicates that the first data point entered is stratigraphically lower than the second position. In the Busk method a negative value means that the first position entered is further from the centre of curvature of the beds than the second position (Fig. 44). In this program the bedding orientation angles must be relative to the coordinate system used to locate the data-point positions.

The advantage of these numerical techniques over the equivalent graphic procedures are obvious when only one calculation is being undertaken but truly impressive when a large series of values are to be calculated rapidly. A few common uses of this program are:

(1) Calculating stratigraphic intervals along traverse lines (Charlesworth and Kilby, 1980) or across existing geology maps.

(2) Calculating stratigraphic thickness in a covered interval during section measuring.

(3) Predicting horizon depth in boreholes given various bedding orientations or borehole locations.

(4) Thickness calculations given bedding-to-core angles.

(5) Thickness calculations given dipmeter values.

As it stands the program calculates one problem at a time; it is easily modified to sum the stratigraphic interval for a series of data points such as outcrops or bedding-to-core angles down a borehole.

Occasionally the user would like more information from the calculations than the stratigraphic thickness. The following values are of potential interest in judging the validity of the calculation or for use in some other task:

(1) Orientation of the intersection of the two bedding planes, fold-axis orientation.

(2) The coordinates of the two points projected onto the plane normal to the fold-axis orientation.

(3) The clockwise pitch angles of the two projected orientations on the plane normal to the fold-axis orientation.

Microsoft BASIC on micro-computers runs interactively. This allows the user to stop the program at any point and determine the value of a variable. The three sets of information described above can be obtained by adding in the following lines to Figure 43:

331 PRINT NT,NP – where values are the trend and plunge of the fold-axis orientation in radians.

421 PRINT X3, Y3, X4, Y4 – yields the horizontal and vertical coordinates on the plane of the profile for points one and two, respectively.

475 PRINT A1,A2 – provides the angles, in radians, of the clockwise pitch of bedding from points one and two on the plane of the profile.

At other times it is desirable to add values calculated outside the program for fold-axis orientations or pitch angles. Again the program can easily be modified to allow introduction of an outside value. Often a standard fold-axis orientation is desired for a large number of calculations within a structural domain. Insertion of the following lines will enable a user-preferred fold-axis orientation to be used:

```
331 INPUT"ENTER NEW TREND AND PLUNGE OF FOLD-AXIS";NT,NP
332 T=NT*PI:P=NP*PI:GOSUB 580:LB=L:MB=M:NB=N
```

Modification of the calculated pitch angle at one or either of the two points is accomplished by first stopping the program and examining the existing values by inserting the following line:

```
475 STOP:PRINT A1,A2
```

The above line yields the present values of pitches in radians; to change these values and start the program execution the following is entered into the computer with the new values replacing the question marks:

```
A1=???:A2=???:CONT
```

The enclosed program (Fig. 43) is a bare-bones version because it does not take advantage of machine-specific commands or mass storage but was designed to be highly portable. It can be typed into any machine with Microsoft BASIC with no changes. Slight modifications may be required for other versions of BASIC. If the thought of typing the whole program is not agreeable it is presently running on a PET and a KAYPRO so any machine compatible with these could get a cassette or diskette copy by sending a blank and a self-addressed mailer to the author. The program could also be easily copied via a telephone hookup. The accompanying Table contains a small set of test data to verify correct entry of the program.

**TEST DATA**

```
X1..Y1..Z1..DD1..DIP1...X2..Y2..Z2..DD2..DIP2........MEAN......BUSK


0...0...0...30...30.....10..10..0...30...30..........-6.83......---

0...0...0...30...25.....10..10..0...30...38..........-7.11.....-7.18

0...0...0...30...38.....10..10..0...30...25..........-7.11......7.18

0...0...0...30...45.....10..10..0..150...45..........-3.54.....-5.66

0...0...0...10...30.....10..10..0...70...40..........-7.19......5.48
```

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# STRATIGRAPHIC AND DEPOSITIONAL RELATIONSHIPS BETWEEN THE BLUESKY MARKER UNIT, GETHING MARINE TONGUE, AND UPPER COAL MEASURES OF THE GETHING FORMATION

## (93O, P)

By A. Legun

A recent correlation of Lower Cretaceous coal measures in the Peace River coalfields (Duff and Gilchrist, 1981) documented the presence of a major marine tongue in the Gething Formation south of Sukunka River (Figs. 45 and 46). This tongue divides the Gething Formation into upper and lower coal-bearing sequences. Prominent coals in the upper sequence include the Bird, Skeeter, and Chamberlain seams of BP Exploration (Canada) Limited's Sukunka property. Deposits of the marine tongue thin to the southeast and thicken to the northwest. They consist of an upward coarsening sequence of interbedded siltstones and sandstones that is free of coal; they commonly contain the marine bivalve *Entolium irenense*. Deposits 'shale out' to the northwest into the Moosebar Formation, while becoming sandy and even pebbly to the southeast where they thin. To the northwest coal drill-hole data from BP's Sukunka and Teck Corporation's Burnt River East properties indicate that the Bird, Skeeter, and Chamberlain seams pinch out (in that order) and are replaced by marine sandstone and siltstone. Similarly, gamma and density logs from petroleum and gas wells show that the upward coarsening sequence of the marine tongue persists to the northwest but loses coal 'density kicks' at the top (for example, *see* Quasar et al Oetco, 6200' to 6600' *in* Duff and Gilchrist, 1981).

The presence or absence of coal may be used as a measure of the areal limit of the upper coal-bearing sequence. This is illustrated on Figures 47 and 48 for the Sukunka-Gwillim Lake area. The data indicates the presence of a deltaic lobe that trends northeast and is bordered by marine deposits of the Moosebar Formation.

Northwest of Sukunka River the upper coal-bearing sequence is absent. Between the Pine and Sukunka Rivers 'lower' Gething rocks are overlain by silty sedimentary rocks of the Moosebar Formation, these being lateral equivalents of the Gething marine tongue. At Peace River Canyon rocks of the 'lower' Gething Formation are overlain by mudstone of the Moosebar Formation.

The top of the 'lower' Gething Formation is in sharp contact with a pebbly and glauconitic marker unit called the Bluesky (Pugh, 1960). The Bluesky is generally regarded as a thin lag deposit formed during initial transgression of the Moosebar Sea. However, it varies considerably in thickness (<1 to 40 metres) and lithology in the Peace-Pine Rivers region, where it consists variably of pebbly mudstone, pebbly arenite, or quartz arenite.

Southward the Bluesky persists as a distinct marker unit to the area of the Sukunka River. There it 'merges' with and forms the base (?) of sandy and glauconitic sedimentary rocks of the Gething marine tongue (for example, in BP Sukunka diamond-drill hole C–35 and on Figs. 45 and 48 of this report). Together these rocks represent sediments deposited in shallow offshore conditions in the Moosebar Sea; they lie near the southern limit of its transgression.

Some workers, for example, oil company personnel and White (1983), classify the entire marine tongue as the Bluesky. For this reason, White's isopach map shows pronounced thickening of the Bluesky in the Gwillim Lake area. Because it is part of the marine tongue, it is clear that the Bluesky disappears as the

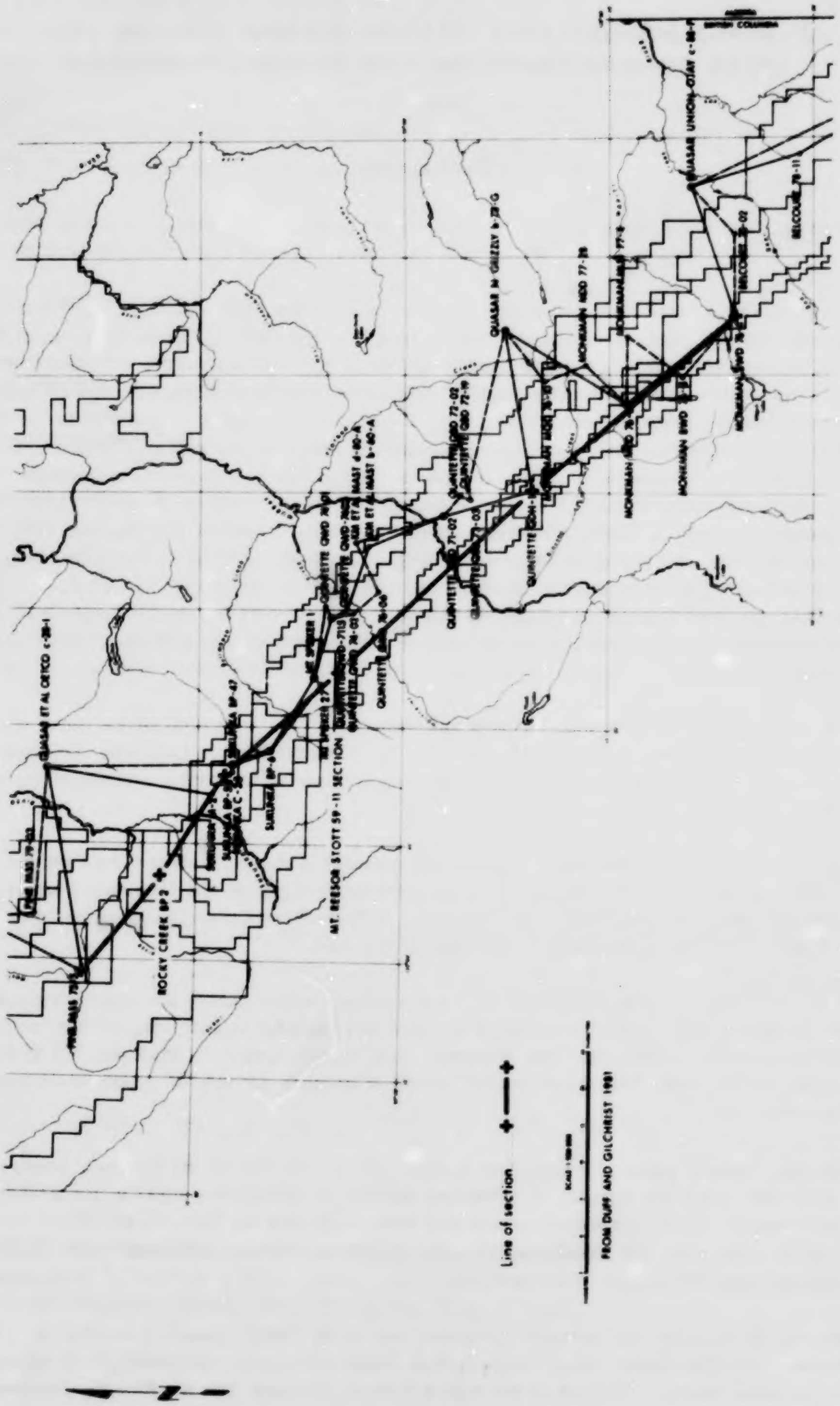

Figure 45. Location map – Peace River Coalfield correlation (from Duff and Gilchrist, 1981).

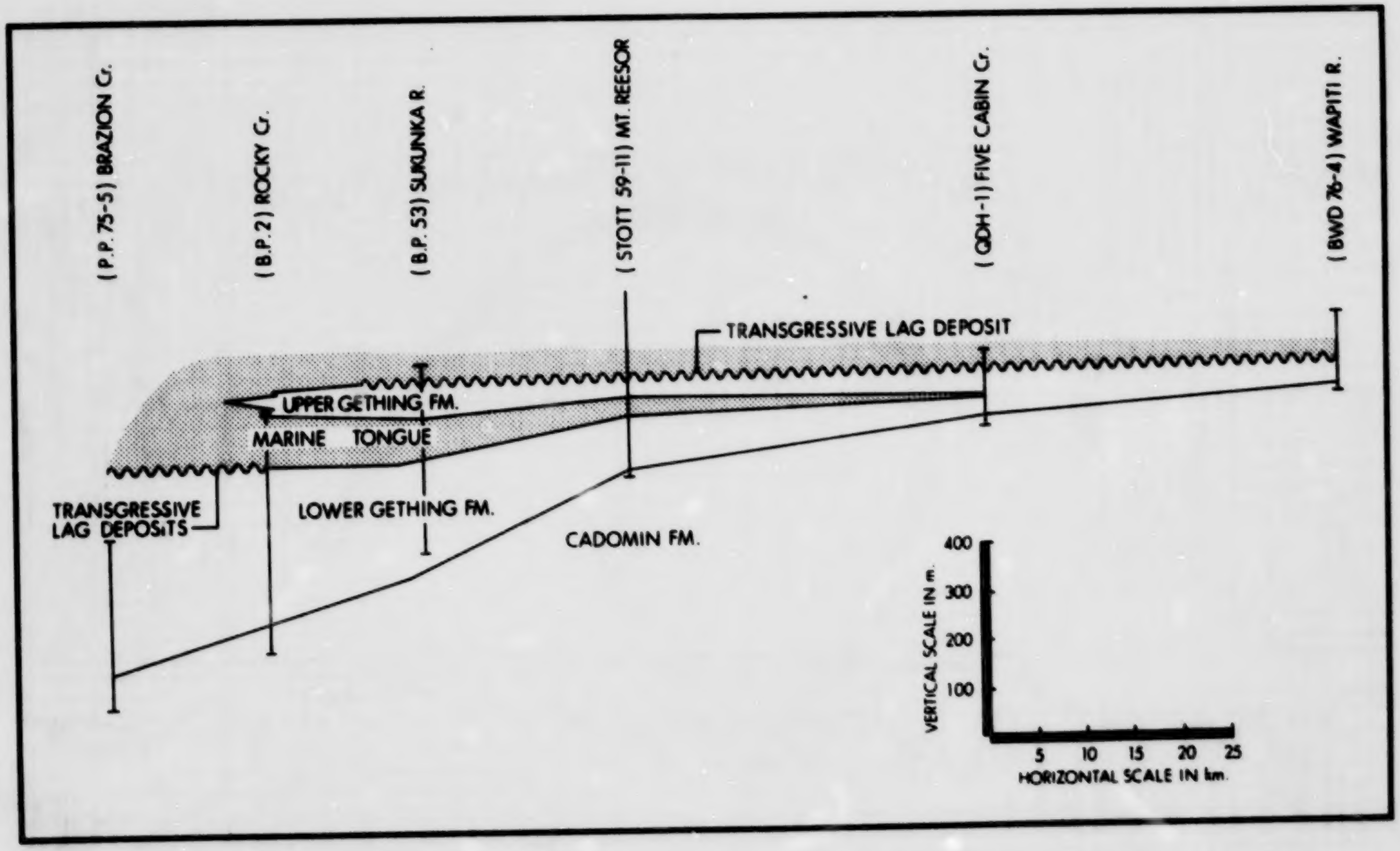

Figure 46. Northwest-southeast line of section showing marine tongue in the Gething Formation. Note the two transgressive lag deposits, they are not stratigraphically equivalent.

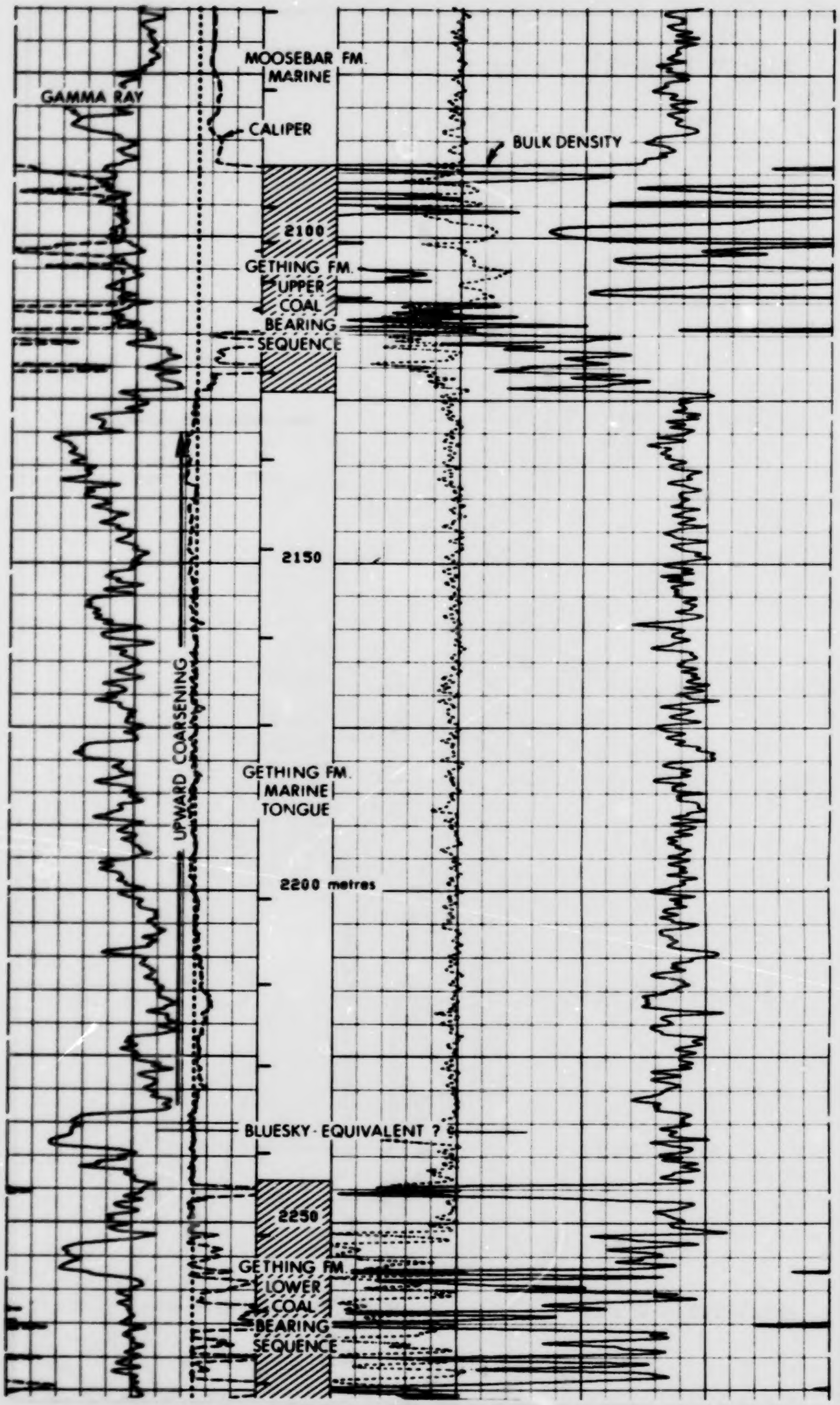

**Figure 47.** Interpretation of gamma ray and bulk density log data for GETTY ET AL GWILLIM c-27-E, 93P/6.

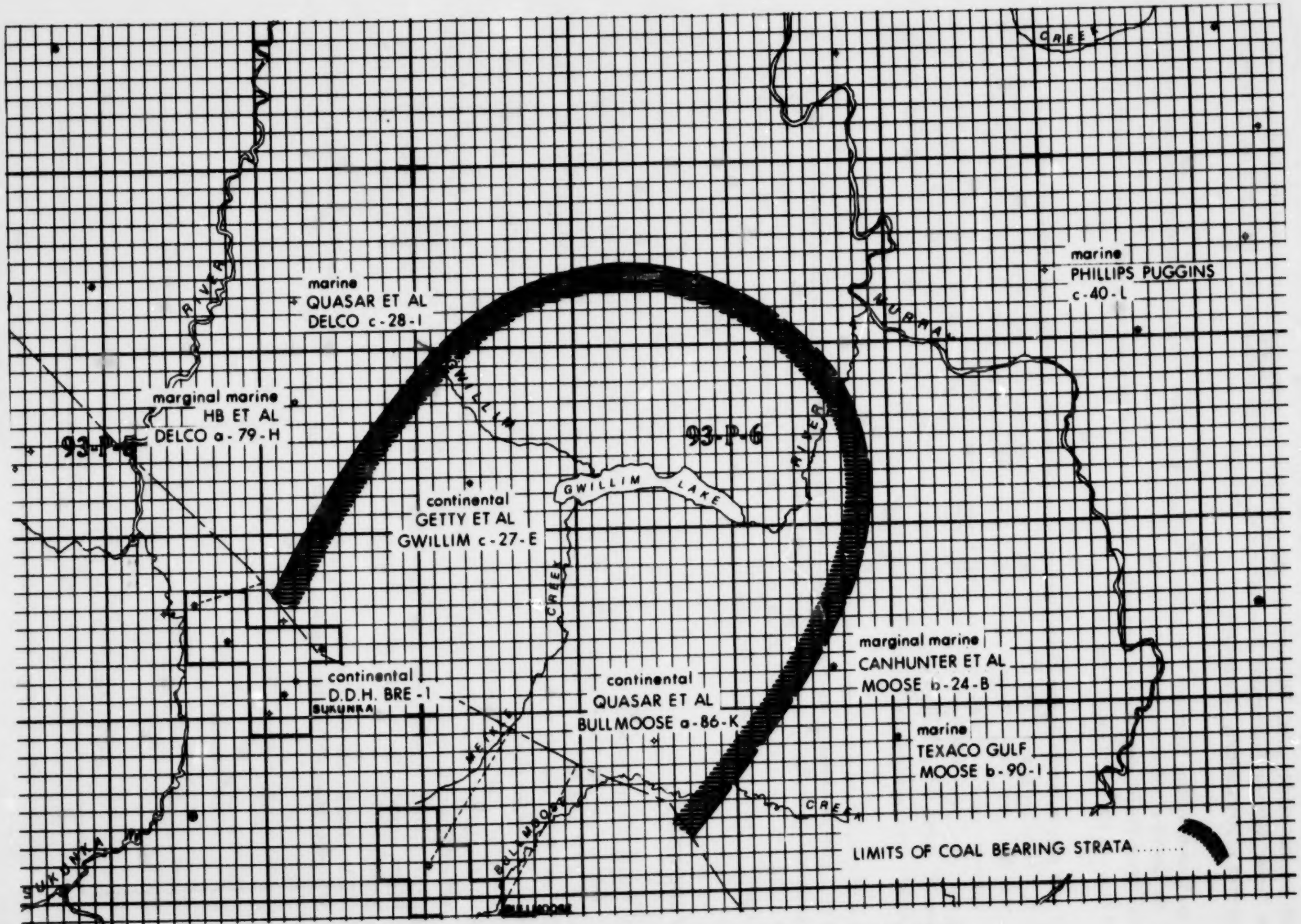

Figure 48. Aerial limits of coal-bearing strata above the Gething marine tongue.

marine tongue pinches out. Southeast of Sukunka River the top of the 'upper' Gething is in sharp contact with another pebbly unit. This unit cannot be correlated or isopached together with the Bluesky on top of the 'lower' Gething Formation; they are deposits of separate transgressions; there is a regressive deltaic sequence stratigraphically between them.

A northeast-trending basement high called the Peace River Arch probably controlled large-scale migration of the land/sea boundary, shallowing of the Moosebar Sea, and orientation of the 'upper' Gething delta lobe. Stott (1974) documented the position of the arch and its effect on sedimentation patterns throughout much of Early Cretaceous time.

Thickest accumulations of the Bluesky appear to coincide with the edges of basins of subsidence . In the south, this occurs where there is rapid thickening of the Gething Formation at the edge of the Peace River Arch at Sukunka River. To the north, substantial thicknesses (up to 40 metres) of Bluesky arenite and conglomerate on the Moberly licenses (Gulf Canada Resources Inc.) and Butler Ridge accumulated along the north and south edges of a major east-west trough of subsidence between the Peace and Pine Rivers (*see* report on Butler Ridge map-area, this volume and Stott, 1968, Fig. 10, p. 31). It is in this trough that the maximum thickness of Gething Formation was deposited.

Areas of maxiumum subsidence would quickly be drowned by marine waters; hinge zones on the edges of basins might be expected to be reworked with longshore drift, beach, and offshore bar development. McLean and Wall (1981) suggested that extensive estuaries formed during transgression of the Moosebar Sea in Alberta; the thickness and distribution of the Bluesky Formation may be related to similar estuaries developed in northeastern British Columbia.

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# BUTLER RIDGE MAP–AREA, PEACE RIVER DISTRICT

## (94B/1)

By A. Legun

## INTRODUCTION

Map sheet NTS 94B/1 comprises the study area; it encloses the eastern end of Williston Lake in the Peace River district of British Columbia (Fig. 49). The W.A.C. Bennett Dam is the most prominent landmark in the area.

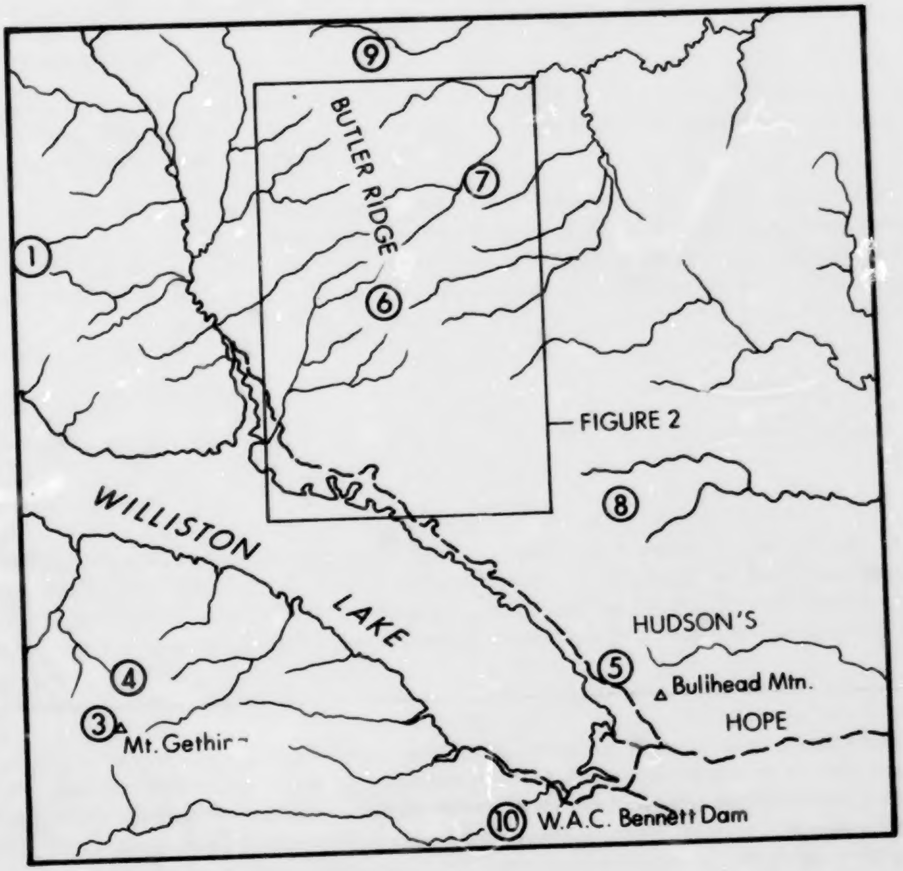

Figure 49. Map showing outline of the project area. Circled numbers refer to locations for which stratigraphic data are available.

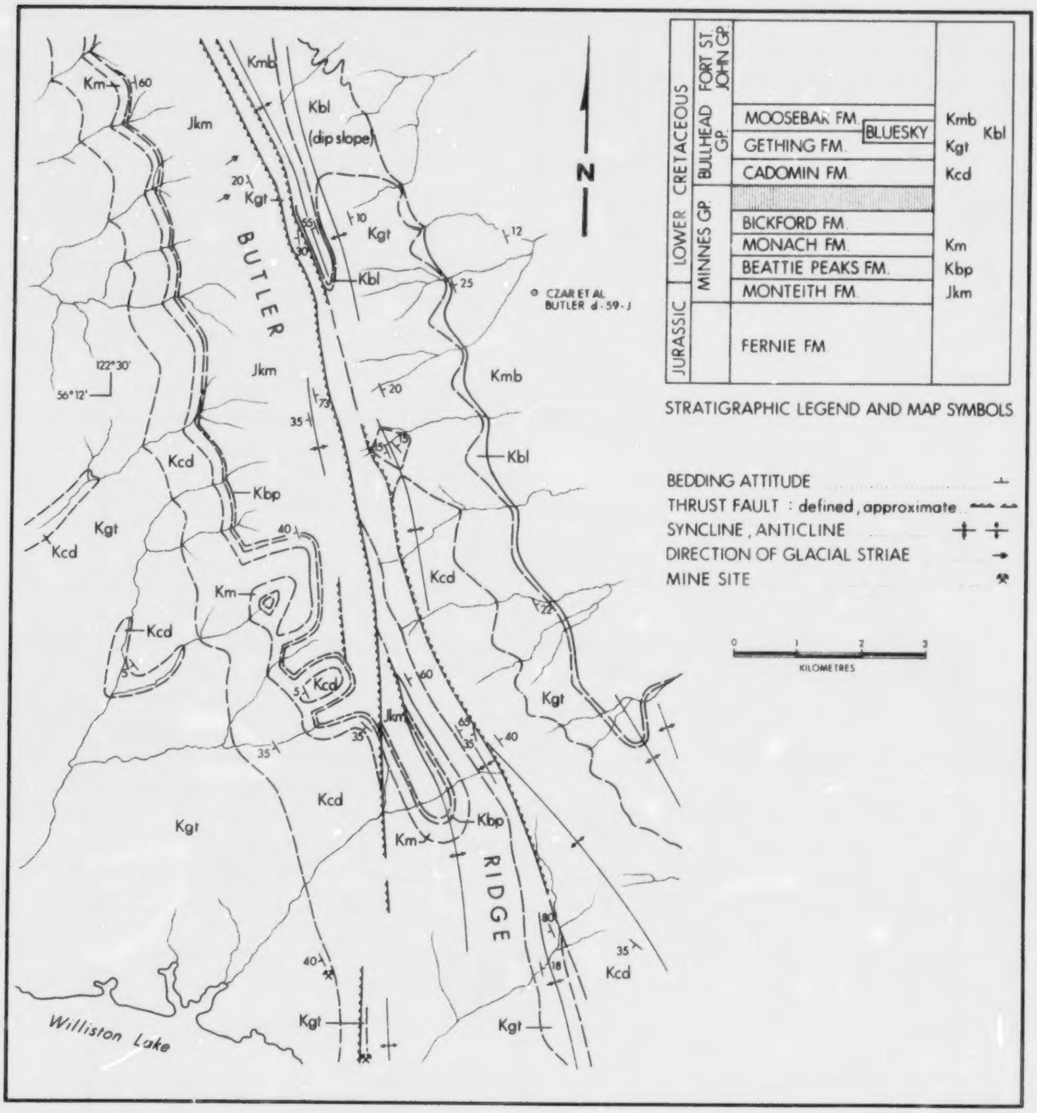

Figure 50. Geology of a portion of map-sheet 94B/1 (mapped at scale 1:50 000).

Fieldwork in 1983 was oriented toward synthesizing the geology from previous work. Previous work includes coal property assessment work by Utah Mines Limited, Hudson's Bay Oil & Gas Company Limited, Amax of Canada Limited, and Cinnabar Peak Mines Ltd. in the areas of Mount Gething, Dunlevy Inlet, Farrell Creek, and Portage Mountain respectively. Data are also available from a number of gas wells drilled in the region.

General stratigraphy and mapping has been done in recent times by Beach and Spivak (1944), Hughes (1964), and Stott (1963, 1968, 1969a, 1969b, 1973), but Beach and Spivak's map remains the only comprehensive compilation of the geology of the area on a 1:50 000 scale.

Beach and Spivak designated strata between the Cretaceous coal-bearing Gething Formation and the Jurassic marine Fernie Formation as the Dunlevy Formation. The term Dunlevy has been discarded and the section divided according to the terminology of Mathews (1946) and Stott (1980) but disputes remain (Hughes 1964).

In the terminology of Stott the Cadomin Formation underlies the Gething Formation. The base of the Cadomin appears to be identifiable and traceable in the map-area. It is marked by a sharp and irregular contact of pebbly arenites with fine-grained, rippled, thin-bedded quartz arenites and siltstones. About 1 centimetre of coal occurs at the contact; there is carbonaceous mottling (rooting ?) below. A similar bedded interval frequently occurs at or very close to the base of the Cadomin Formation as defined by other criteria (*see* following). Recognizing the base of the Cadomin facilitated sorting out the stratigraphy of the underlying Minnes Group.

The stratigraphic sequence must be mapped with caution. The Cadomin Formation and the Minnes Group are both arenaceous sequences; dip-slope exposures are particularly prone to incorrect designation unless a check with a nearby vertical section is made.

Mapping and air-photograph examination outlined folded and faulted strata that give more complex map unit patterns than that presented in previous maps of the area (Fig. 50). For example, dip-slope remnants of the Cadomin Formation are preserved high on the backs of cross ridges to the main Butler Ridge which otherwise is underlain by the Monteith Formation. Deep in the valleys that drain east Mount Gething, the Cadomin Formation is exposed; dips of its contact with the Gething are generally about the same as the gradient of the valley.

## GENERAL STRATIGRAPHY

### MONTEITH FORMATION

The Monteith Formation consists of thick units of white rippled quartz arenite interbedded with grey to tan rippled shales and arkosic wackes. Exposure of the Monteith Formation often form scarps of quartz arenite that exceed several tens of metres in height. Consequently, the Monteith Formation constitutes much of the high and steep exposure on Mount Gething, south Mount Gething (immediately south of the map-area), and Butler Ridge.

Re-examination of a section measured by Beach and Spivak (1944) on the north amphitheatre of Mount Gething indicates that 603 metres of the formation are present. The writer did not observe the base but Beach and Spivak's data suggest that the lowest 25 metres are in the transition beds to shale of the Fernie Formation. It is not always clear, especially in logs, which quartz arenite in contact with shale comprises the top of the Monteith Formation. As a result there are various interpretations of the stratigraphy between the Monteith and Cadomin Formations (for example, Hughes, 1964; Karst, 1981). Compiled thickness data suggest that the formation thins eastward (accompanying table).

## COMPILATION OF STRATIGRAPHIC THICKNESS DATA
(*SEE* FIGURE 49 FOR LOCATIONS)

| | FERNIE FORMATION | MONTEITH FORMATION | BEATTIE PEAKS FORMATION | MONACH FORMATION | CADOMIN FORMATION | GETHING FORMATION | BLUESKY |
|---|---|---|---|---|---|---|---|
| | *metres* | *metres* | *metres* | *metres* | *metres* | *metres* | *metres* |
| 1. Quasar et al Dunlevy a-40-L | 100 | 505 | 200 | | — | — | — |
| 2. Rainbow Rocks | — | — | 210 | | — | — | — |
| 3. Mount Gething – North | — | 603 | >120 | — | — | — | — |
| 4. Mount Gething – Northeast | — | — | — | ~100 | — | — | — |
| 5. Butler Ridge – South | — | — | ~30 | ~120 | — | — | — |
| 6. Butler Ridge – North | — | — | ~50 | ~125 | — | — | — |
| 7. Czar et al Butler d-59-J | 120 | 415 | 50 | 95 | ~260 | ~325 | 40 |
| 8. FPC – Richfield, Brenot Creek No. 1 | 34 | 382 | 110 | | — | — | — |
| 9. Amax Coal Co. Inc., diamond-drill hole BR-1 | — | — | — | — | — | 275 | 40 |
| 10. Peace River Canyon | — | — | — | — | — | 550 | <1 |
| 11. West Cdn Moberly Lake 11-36-80-25 | 120 | 282 | 61 | — | 119 | 250 | 6 |

## BEATTIE PEAKS FORMATION

The Beattie Peaks Formation consists of dark, burrowed, and carbonaceous siltstones, ferruginous shales, fine-grained rippled arenites, and quartz arenites. The stratigraphic interval is normally recessive but less so in this map area than to the west. Best exposures comprise the top 125 metres of Beach and Spivaks' section on the west 'table-top' of Mount Gething. To the south, on the South Mount Gething property, Utah Mines considers that about 40 metres of this formation are present. East of Mount Gething the formation is difficult to recognize, both on logs and in section. In the area of Bullhead Mountain it forms a thin (30-metre ?) shaly transitional interval between quartz arenites below and flaggy arenites above, but both lithologies are much interbedded. Its upper contact is sharper on Butler Ridge to the north. The formation thins eastward from the Carbon Creek area (where it is ≥230 metres); the Butler Ridge/Bullhead Mountain area is probably near the eastern limit where it can be recognized.

## MONACH FORMATION

The Monach Formation consists of massive to flaggy arenite units. Arenite units are ledge forming but these are not as prominent as scarps of the Cadomin or Monteith Formation. Platy crossbedding and general lack of both pebbles and log casts helps to differentiate these arenites from those of the Cadomin Formation, which they otherwise resemble. Some units fine upwards in grain size with flaggy beds overlying a massive base (for example, northwest end of Butler Ridge). At Rainbow Rocks lateral pinching of units is apparent.

Tentative identification of the Monach Formation on Bullhead Mountain was made last year (Legun, 1982); it is apparently confirmed by a section exposed immediately to the south of the highest knob on Butler Ridge where approximately 125 metres of massive and crossbedded arenite (Plate VI) underlie the pebbly Cadomin Formation. Similar flaggy arenites directly underly the Cadomin Formation on the south and west sides of Bullhead Mountain, at Rainbow Rocks, and on the northeast flank of Mount Gething. Coarse-grained quartz arenite is also present and may grade into arenite without an apparent bedding contact. Gamma log data from gas wells indicate that some recessive zones between arenite units are carbonaceous.

Immediately below the Cadomin Formation on the north side of Portage Mountain near the British Columbia Hydro line is an anomalous section consisting of tens of metres of massive coarse quartz arenite overlain by interbedded quartz arenite, shale, and coal. Bedding dips indicate that this sequence underlies pebbly Cadomin Formation exposed in a road cut leading to the W.A.C. Bennett Dam. This contrasts markedly with arenites immediately to the north on Bullhead Mountain that are apparently in the same stratigraphic position.

It is difficult to judge the thickness variation in the Monach Formation since, together with Beattie Peaks shale, it may form a single upward coarsening sequence. Where a reasonable separation of lithology has or can be made (accompanying table), a thickness not exceeding 125 metres is indicated. This is not a significant change from thicknesses to the west (Mathews, 1946).

Plate VI. Outcrop of cross-bedded Monach Formation arenite, Butler Ridge area.

## CADOMIN FORMATION

The Cadomin Formation is characterized by a series of pebbly arenite units that form scarps or ledges separated by recessive interbeds. This corresponds to a large blocky gamma response on geophysical logs. On the whole units are only sparsely pebbly with pebbles concentrated in lenses near or at the base. Log casts at the base are also typical. Carbonaceous shales and thin coals constitute parts of the recessive intervals. The base of the Formation is distinct and it grades into the Gething 'coal measures' by thinning of arenite units and loss of pebbly aspect.

The Cadomin Formation is well distributed through the map area; a complete section may be present on Butler Ridge above the headwaters of Gravel Hill Creek. Here steep-dipping arenite units are exposed for a considerable distance along strike. They are lens-like and fine upward from conglomerate at the base. This and other characteristics, for example log impressions, suggest a fluvial origin for these units.

Clasts in the Cadomin are up to 5 centimetres in long diameter; no pronounced change in clast size from west to east was noted. A maximum thickness of 260 metres is indicated in Czar et al Butler gas well. Sections measured by Stott and mapping by the writer suggest a thickness of 200+ metres in the map-area.

## GETHING FORMATION

The Gething Formation is a typical 'coal measure' sequence. It consists of interbedded arenites, siltstones, shales, mudstones, and coals; fossil plant material is abundant. The type section is at Peace River Canyon, immediately below the W.A.C. Bennett Dam, on its west side. Interesting features of Peace River Canyon exposures include a preserved tree trunk with annual growth rings (Legun, 1982).

In the map area the Gething Formation is virtually free of conglomerate; on the whole it is distinguishable as a map unit from the Cadomin Formation. Thick units of Cadomin pebbly arenite pass laterally by pinch-out into coal measures of the basal Gething Formation (for example, at old Reschke mine). Thus, positioning of the basal contact varies from place to place. On the east side of Butler Ridge a sudden decrease of prominent sandstone 'ribs' of the Cadomin Formation visible on air photographs marks the mapped contact with the Cadomin Formation. The top of the Gething section is defined by a distinct marker unit called the Bluesky (discussed later).

The thickness of the Gething Formation varies significantly within the map-area. To the northeast coal drill hole BR–1 and gas well data (Czar et al Butler) indicate a thickness of 275 and 325 metres respectively (Bluesky excluded). In the Peace River Canyon, 28 kilometres to the south, it is 550 metres. Just west of the canyon at Mount Gething, Utah Mines calculates that 670 metres of Gething strata were initially deposited. This increases to over 1 000 metres to the west in the Carbon Creek area. Well to the south of the map-area toward Pine River the formation thins again, defining a basin of subsidence between the Peace and Pine Rivers extending east-west. This basin of maximum deposition was outlined by an isopach map of Stott (1968, Fig. 10, p. 31); it appears to be even more trough-like in form west of Moberly Lake.

The thickness of the Bluesky marker unit also varies significantly in the map-area. Lithologically the unit consists of glauconitic chert pebble mudstone to pebbly arenite to well-sorted quartz arenite. Lithologic contrast is strong with the overlying Moosebar shales and underlying Gething coal measures. In the Peace River Canyon area the Bluesky is less than one metre thick and consists of matrix-supported chert pebbles in mudstone. To the north, in the Ruddy Creek area, thickness has increased to 40 metres and it consists of 24 metres of quartz arenite overlain by 17 metres of closely packed pebble conglomerate (diamond-drill hole BR–1). The sequence coarsens upward in 'step-like fashion'. Hughes (1972) separated the quartz arenite from the conglomerate and called it the 'Ruddy Member' of the Gething Formation; however, from gamma log response and physical character (no coal) it is apparent that the conglomerate and the arenite form the same depositional unit.

Beach and Spivak identified *Discranodonta* in the conglomerate at Ruddy Creek. This pelecypod, together with upward coarsening and fair to good sorting of clasts within discrete layers, suggests that the Bluesky unit is of shallow marine origin. The source of the clasts is an enigma.

## COAL GEOLOGY

Though thin coals are present in the Cadomin Formation and carbonaceous zones occur in the Minnes Group, the Gething is the only formation of economic significance. The Gething Formation in the Peace River Canyon area has at least 20 named seams but they rarely exceed 1 to 1.5 metres in thickness. Utah Mines has correlated some with seams underlying its East Mount Gething property (Louise, Milligan, and Riverside seams). The Trojan and Superior seams of the Peace River Canyon area are correlated southward into Bri-Dowling and South Mount Gething properties but their presence north of Williston Lake is in doubt.

Coal outcrops are easily accessed along the Dunlevy Creek Road, the road to W.A.C. Bennett Dam by Portage Mountain, and the road going to Carbon Lake by Mount Gething.

In general, maximum coal seam thickness increases from the Williston Lake area southward to the Pine Pass region, where occasional seams are 4 metres or more thick. The map area probably represents the northern limit of economic coal in the Gething Formation.

In the north half of the map-area, drilling by Amax in 1971 and 1972 did not intersect seams thicker than 1.2 metres. Hudson's Bay Oil & Gas intersected a 3-metre-thick high-ash coal seam in the middle Gething just east of Dunlevy Inlet. On the eastern slopes of Mount Gething the Riverside seam is a maximum 3 metres thick but averages half that thickness.

A coal rank study by Hacquebard (1974) of the Peace River Canyon section indicated that coal reflectance values ranged from 1.05 at the top to 1.36 at the base of the Gething Formation. This indicates that coals in the area are medium to high-volatile bituminous in rank. Company data also indicates that coals in the area are non-coking (low FSI).

## PRE–CADOMIN UNCONFORMITY: DISCUSSION

Stott (1969, 1973) considers that the Cadomin Formation lies on Beattie Peaks strata in the Butler Ridge area at Rainbow Rocks and on Bullhead Mountain and that intervening strata, the Monach and Bickford Formations, were removed by erosion. Stott rejects the idea that intervening formations disappear by eastward thinning; he considers the base of the Cadomin Formation to mark a major unconformity with progressive bevelling of underlying formations in a northeast direction. This has been disputed by Hughes who argued that the carbonaceous Bickford Formation, his Brenot Formation, persisted eastward from the Carbon Creek area. The writer agrees with Stott; apparently Hughes' Brenot Formation is based on incorrect identification of the top of the Monteith Formation in the French Petroleum Company – Richfield, Brenot Creek No. 1 well.

Stott's unconformity probably corresponds to the distinct contact observed at the base of the Cadomin lithologic sequence. This unconformity, however, is not as profound as suggested by Stott; the Monach Formation is present and loss of thickness of the Minnes Group is due in part to stratigraphic thinning, not erosion.

## STRUCTURE

As noted by Beach and Spivak (1944), the major structural features of the Peace River foothills are narrow zones of anticlinal folds, commonly broken by high-angle thrust faults, separated by broad synclinal basins of gently folded strata (for example, the Dunlevy syncline). In the map-area, two major fault zones are present. On Butler Ridge Monteith quartz arenites are thrust over the Gething Formation. To the south this major thrust splits into a series of thrusts which have smaller displacement and are separated by tight synclines and anticlines. These tight anticlines open into box-like forms with sharp-kinked limbs. To the north only dip-slope remnants of the Cadomin Formation are preserved high on the 'back' of the thrust plate; to the south, where the structures open up, Cadomin Formation forms the bulk of the exposure of the anticline and syncline pairs.

On the east flank of Mount Gething a major fault thrusts Monteith quartz arenite over Cadomin pebbly arenites. This thrust continues on the east side of south Mount Gething. West of the thrust, strata on Mount Gething and south Mount Gething are flat lying; further west they steepen to the west over a kink fold. This suggests that the structure forming the flat peak tops of both mountains is a box fold with its east limb overturned above the thrust. Beach and Spivak's map, however, shows the kink on Mount Gething to be a thrust which continues as the thrust on the east flank of south Mount Gething; mapping by the writer suggests that this is incorrect.

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# BILL PROSPECT
## (94E/13)

### By T. G. Schroeter

## INTRODUCTION

The Bill prospect is located 135 kilometres southeast of Dease Lake at latitude 57 degrees 45 minutes north and longitude 127 degrees 45 minutes west, in the Liard Mining Division (Fig. 51). Access is by helicopter from either Sturdee Valley airstrip, which lies 70 kilometres to the southeast or the Hyland Post airstrip which lies 30 kilometres to the southwest. The claims (Bill 1, 2, and 3) total 43 units; they are owned by Cominco Ltd. but were operated in 1982 and 1983 by DuPont of Canada Exploration Limited. Most of the area of the claims lies above treeline. Surveys by Cominco in 1981 and by DuPont in 1982 outlined a large gold-arsenic soil anomaly.

The writer spent three days on the property in July 1983.

## PROPERTY GEOLOGY

Basalt forms the base of the volcanic pile in the area of the property; it is overlain by a dominantly andesitic tuff sequence. The tuffs are overlain by a complexly intercalated sequence of carbonatized volcanic sedimentary rocks ranging in composition from andesite to rhyolite. No significant volume of intrusive rock was noted on the property.

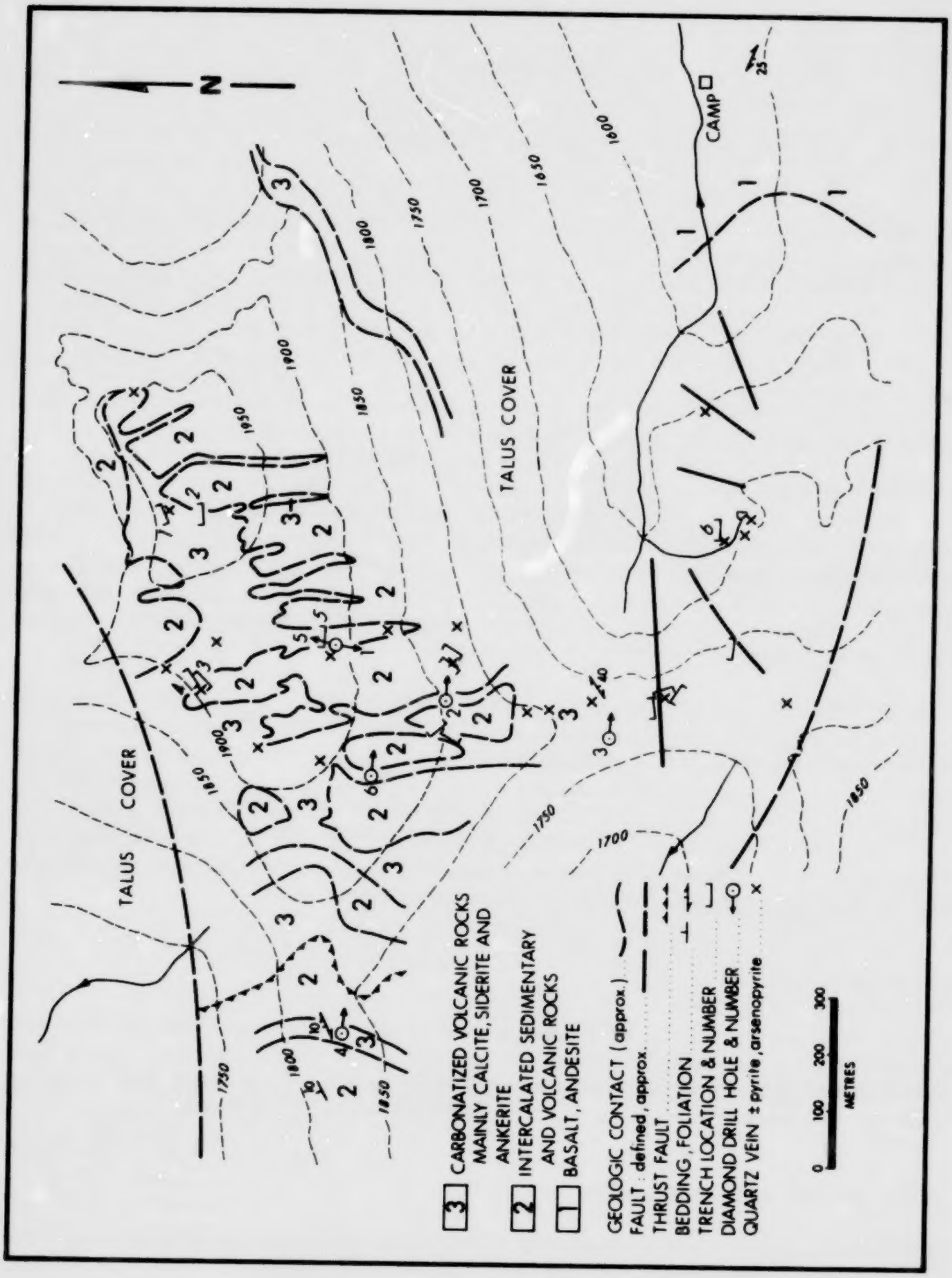
Intercalated sedimentary and volcanic rocks that underly the claim group have been regionally metamorphosed to lower greenschist grade; most are now schist and phyllite. At least two phases of folding took place and boudinaging of quartz and/or carbonate lenses is common. The volcanic rocks are mainly tuffaceous, ranging in composition from andesitic to rhyolite; in part composition depends on the percentage of quartz eyes present. Locally there are flows of massive or pillowed basalt. The sedimentary rocks include weakly to moderately carbonatized siliceous siltstone; these are often intercalated with intermediate to acidic tuffs, crinoidal limestone, calcareous sandstone, and quartzite. A distinctive sequence of pelite and greywacke structurally overlies the volcanic sequence.

## STRUCTURE

All the rocks on the claim group are foliated to some degree and the foliation has moderate dips. Boudinaging of quartz lenses or pods is common in more mafic units. Common carbonate ± quartz knots lie parallel to banding in well bedded crinoidal limestone. Kink bands in the sheared felsic tuffs and folding of boudinaged quartz knots and veins in basic tuffs indicates at least two periods of deformation.

## MINERALIZATION AND ALTERATION

Gold with arsenopyrite occurs as late-stage fracture fillings in quartz ± carbonate veins and pods, as dry veinlets, and also as disseminations and stockworks in altered tuffs; arsenopyrite is the most abundant metallic mineral. Pyrite is ubiquitous in the altered tuffs with at least two stages observed. Chalcopyrite occurs in trace amounts. Carbonate veinlets carrying euhedral quartz grains and pyrite veinlets cut quartz



N
TALUS COVER
TALUS COVER
CAMP
1750
1800
1850
1900
1950
1700
1650
1600
3 CARBONATIZED VOLCANIC ROCKS MAINLY CALCITE, SIDERITE AND ANKERITE
2 INTERCALATED SEDIMENTARY AND VOLCANIC ROCKS
1 BASALT, ANDESITE
GEOLOGIC CONTACT (approx.)
FAULT: defined, approx.
THRUST FAULT
BEDDING, FOLIATION
TRENCH LOCATION & NUMBER
DIAMOND DRILL HOLE & NUMBER
QUARTZ VEIN ± pyrite, arsenopyrite
0
100
200
300
METRES

Figure 51. Sketch map of the Bill prospect, 94E/13 (after company plans).

± arsenopyrite veinlets. Quartz veins range in width from less than 1 centimetre to 1.5 metres. Most are steeply dipping and cut stratigraphy. Fault zones may be an important guide to mineralization. Apparently intense quartz-sericite alteration has replaced basic volcanic rocks along zones of structural weakness; gold mineralization is most abundant where quartz-sericite alteration is most intense. Quartz veins within quartz-sericite altered zones are most likely to be in the cores of the altered zones. Overall, arsenopyrite abundance does not correlate well with gold values; locally, however, the two are closely correlated.

## WORK DONE

During 1983, DuPont diamond drilled approximately 1 175 metres in a six-hole program designed to test previous soil geochemical anomalies, to test geophysical anomalies, and to test analyses from hand-blasted trenches.

## ACKNOWLEDGMENTS

The writer would like to thank DuPont (especially Tom Drown and Joanne Forbes) for providing access to the property and their kind hospitality while on the property.

# TOODOGGONE RIVER AREA

## (94E)

By T. G. Schroeter

## INTRODUCTION

The Toodoggone River area lies approximately 300 kilometres north of Smithers; it is now recognized as a significant precious metals camp. Access into the area continued to be by aircraft only, mainly from Smithers.

The writer spent two 1-week periods in the area completing regional mapping north of the Toodoggone River. The mapping was done in conjunction with Andre Panteleyev and Larry Diakow at a scale of 1:25 000. A preliminary map of the Toodoggone area, at a scale of 1:50 000, will be available in early 1984.

## WORK DONE

Brief visits were made to the Golden Lion, JD, and AL properties and two stratigraphic sections located north of Moyez Creek were examined.

Work carried out by companies in the Toodoggone River area included the following:

(1) *Kidd Creek Mines Ltd.*

   (a) JD (Mineral Inventory 94E-32) – 1 200 metres of surface trenching in 22 trenches on the Gumbo and Gasp zones.

   (b) AL (Mineral Inventory 94E-78, 79) – 2 400 metres of surface trenching in 43 trenches including the Bonanza and Ridge zones.

(2) *SEREM Inc.*

   (a) Lawyers (Mineral Inventory 94E-66) – 3 054.2 metres of diamond drilling in 17 holes (eight on Cliff Creek, seven on Duke's Ridge, and two on AGB).

   (b) Lawyers – 1 800 metres of backhoe trenching on Cliff Creek and Duke's Ridge zones.

   Minimal work was done on a few other claims within the area in order to maintain them in good standing.

(3) *Newmont Exploration of Canada Limited*

   (a) Shas (Mineral Inventory 94E-50) – 674 metres of diamond drilling in nine holes and 20 blasted trenches explored the main zone and a new area, the Creek zone, with encouraging results. Gold-silver-bearing quartz vein stockworks occur within a 1 000 by 1 600-metre area of altered Toodoggone tuffs.

   (b) Golden Lion (Mineral Inventory 94E-77) – 21 backhoe trenches totalling 1 908 metres in length outlined an area of significant silver mineralization.

Regional exploration was also carried out by:

(4) *DuPont of Canada Exploration Limited*

Pel — 139 metres of diamond drilling was done in two holes on an alteration zone in Toodoggone 'grey dacite'.

(5) *Taiga Consultants Ltd.*

Property work, including prospecting, geological mapping, and sampling, was carried out on the Mets, Belle, and Saunders claims.

(6) *Asitka Resource Corporation*

Grace (Mineral Inventory 94E-47, 48, 49) — the company carried out approximately 500 metres of diamond drilling to test copper-zinc-gold mineralization in skarn zones along marble-granodiorite contacts and gold mineralization in siliceous zones and in chloritic veins within coarse pyritic meta-siltstone.

(7) *Western Horizons Resources Ltd.*

Golden Stranger (Mineral Inventory 94E-76) — conducted geological mapping and prospecting on the Dave Price and Gord Davies claims.

## ACKNOWLEDGMENTS

The writer acknowledges the hospitality and logistical support offered in the field by the following companies: DuPont of Canada Exploration Limited, Newmont of Canada Exploration Limited, Kidd Creek Mines Ltd., SEREM Inc., Central Mountain Air Services Ltd., and Airlift Corporation.

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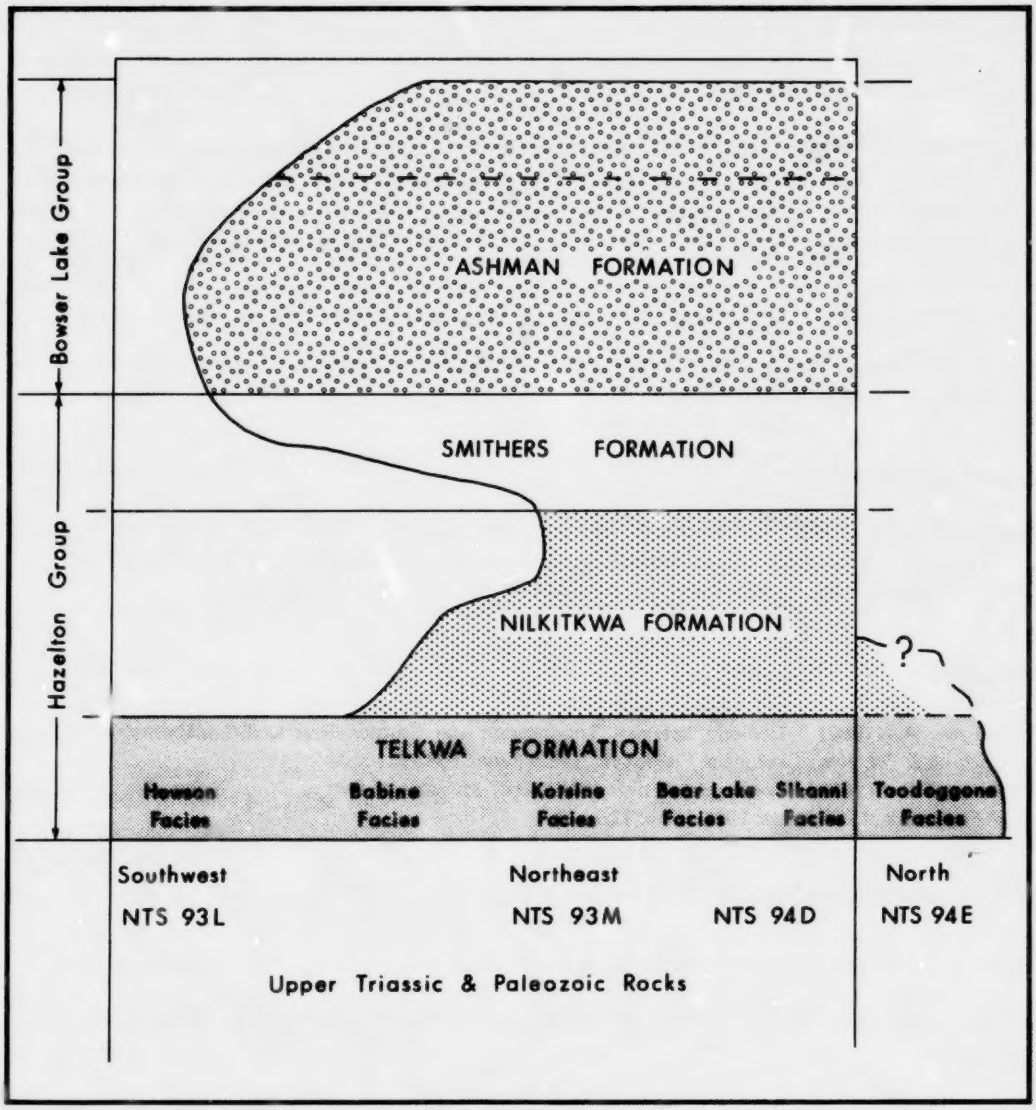

Figure 52. Time stratigraphic cross-sections of the Hazelton and enclosing Groups (modified from Tipper and Richards, 1976).

# STRATIGRAPHIC POSITION OF 'TOODOGGONE VOLCANICS'
## (94E/2, 3, 6, 7, 11, 12, 13)

### By A. Panteleyev

Recent geological mapping by Gabrielse (1976), Gabrielse, *et al.*, (1976, 1977), Panteleyev (1982, 1983), and Diakow (this volume) has delineated the extent and described the nature of the 'Toodoggone volcanics' of Carter (1972). The 100 by 25-kilometre belt of volcanic rocks has been the focus of much recent exploration for epithermal precious metal deposits (Schroeter, 1982, 1983). Interest in the area is expected to continue at a high level for some time. A preliminary map at scale 1:50 000 summarizing recent lithostratigraphic work by L. J. Diakow, A. Panteleyev, and T. G. Schroeter will be released in the spring of 1984.

The Toodoggone volcanics are a Jurassic, subaerial, intermediate, calc-alkaline to alkaline, predominantly pyroclastic assemblage. They unconformably overlie Upper Triassic Takla rocks. The contact was observed in three localities; in each, Takla pyroxene basalt flows are overlain by biotite-bearing crystal ash tuffs above either a gentle angular unconformity or a disconformity.

The lateral boundaries of the Toodoggone volcanic belt are well defined in most areas. South of Finlay River (94E/2) the volcanic rocks can be traced 1 kilometre into McConnell Creek map-area (94D). There they form a thin erosional remnant on a 'basement' of Takla rocks (Panteleyev, 1982). The southwestern boundary consists of steep reverse faults that juxtapose Toodoggone rocks against Takla and older Asitka rocks (Diakow, 1983). The southeastern boundary consists of stacked panels of Asitka and Takla rocks thrust onto Toodoggone rocks (Panteleyev, 1982). In the central part of the volcanic belt, north of Finlay River, Toodoggone volcanics are commonly in fault contact on the west and east with Takla and undivided Hazelton rocks (predominantly feldspar porphyry flows). Locally the boundary is marked by granodiorite intrusions. The northwesterly margin of the volcanic belt and the northern boundary are overlapped near Chukachida River by clastic rocks of the Cretaceous to Tertiary Sustut Group.

Radiometric dates from the Toodoggone volcanic rocks range from 179 to 204 Ma; coeval granitic stocks intruding the volcanics range from 181 to 207 Ma (Carter 1972; Cann and Godwin, 1980; Gabrielse, *et al.*, 1980; and Panteleyev, 1983). These indicate an Early Jurassic age for Toodoggone volcanism. Faunal evidence is scarce except for one Bajocian locality (earliest Middle Jurassic) from the upper part of the volcanic unit reported by Gabrielse, *et al.* (1976) and Tipper (1976); no other fossil localities have been found. No additional fossils were discovered during recent mapping although a number of sites contain plant debris.

Judging from the radiometric data and field relationships at least the basal, Lower Jurassic part of the Toodoggone volcanics is correlative with the Telkwa Formation as defined by Tipper and Richards (1976). The rocks would constitute a northern extension into Toodoggone map-area (94E) of the Telkwa Formation of the Hazelton Group. In accord with their scheme of five 'facies', belts of similar depositional type within the Telkwa Formation, the basal Toodoggone pyroclastic volcanics can be considered to be a sixth facies – the 'Toodoggone subaerial facies'. The 'facies' relationship is illustrated on Figure 52, a modification of Tipper and Richards' Figure 12 (1976).

Furthermore, as mapping proceeds it is probable that other Toodoggone rocks younger than Telkwa Formation, like the Bajocian site reported by Gabrielse, *et al.* (1976), will be documented. The younger Toodoggone rocks most likely occur north of Toodoggone River in the Moyez Creek-Tuff Peak area where thick flows and lesser sedimentary units with interbedded siliceous tuffs and marls overlie typical Toodoggone ash flows (*see* Diakow, this volume).

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# GEOLOGY BETWEEN TOODOGGONE AND CHUKACHIDA RIVERS
## (94E)

By L. J. Diakow

Regional mapping in the Toodoggone River area was extended in 1983 to include areas underlain by Toodoggone volcanic rocks (Gabrielse, *et al.*, 1977) not previously mapped by Ministry personnel (Panteleyev, 1982, 1983; Schroeter, 1981, 1982; Diakow, 1983). Approximately 300 square kilometres between the Toodoggone and Chukachida Rivers were mapped during July and August at scale 1:50 000. The objectives of mapping were to determine the distribution, stratigraphy, and lithologic nature of Toodoggone rocks and to define their contact relationship with adjacent rocks.

## PHYSIOGRAPHY

The area underlain by Toodoggone volcanic rocks is characterized by rounded mountains and ridges up to 1 900 metres in elevation separated by broad valleys. Outcrops are confined to steeper portions of ridges and to banks of creeks in deeply incised valley bottoms. Along the northern periphery of the surveyed area an abrupt change in relief marks the transition from Toodoggone volcanic to Takla volcanic rocks.

## STRATIGRAPHY

Toodoggone volcanic rocks were subdivided into five lithostratigraphic units. These map units were established by 'grouping' volcanic members with similar mineralogy, primary texture, clast morphology, and environment of deposition. The distribution of map units and stratigraphy is shown on Figures 53 and 54. In order of relative abundance, the volcanic assemblage is made up of ash-flow tuffs, lava flows, interbedded pyroclastic air-fall deposits, epiclastic rocks, and lesser chemical sedimentary rocks; mainly siliceous marls. The rocks are predominantly andesitic in composition, although quartzose andesite and trachyandesite are present locally. The five map units are as follows:

**UNIT 1:** These rocks underlie the west half of the surveyed area. The unit can be subdivided into a lower member (unit 1A) composed primarily of bedded air-fall deposits and an upper member (unit 1B) dominated by ash-flow tuff with a less abundant air-fall component.

Unit 1A is a heterogeneous succession of mainly crystal-lithic tuffs and some ash-flow sheets with limited lateral extent. The tuff sections normally are crudely layered although bedding is usually not evident where randomly dispersed lithic fragments supported by a matrix of plagioclase, hornblende, and biotite crystals and lithic ash occurs. Subangular quartz phenocrysts 1 to 3 millimetres in size and minute euhedral apatite crystals are present in this unit. Lithic fragments generally have rounded to subangular outlines and range in size from lapilli to blocks. Typically, the fragments are non-vesiculated, varicoloured, and porphyritic. The contact between layered air-fall tuff and ash-flow tuff is characterized by an increased resistance to weathering of ash-flow outcrops; possibly resulting from some welding accompanied by post-emplacement compaction.

Unit 1B is characterized by a preponderance of ash-flow sheets with intercalated crystal-lithic tuffs. The tuffs display little variation in composition or texture and are composed of plagioclase, hornblende, biotite, and subordinate quartz and apatite phenocrysts set within a pink to brick-red vitric matrix. Layering

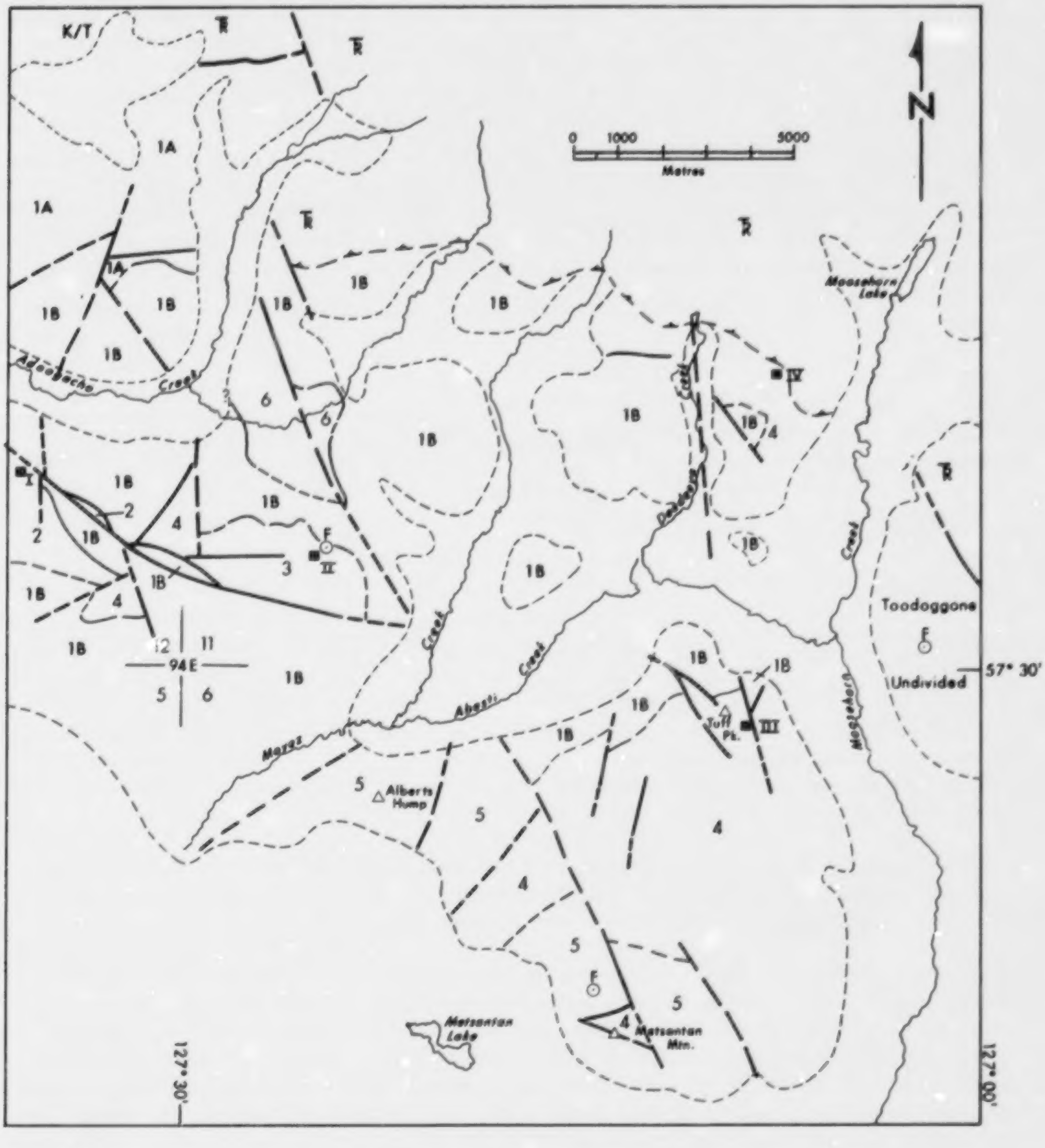


Figure 53. Geology between Toodoggone and Chukachida Rivers.

caused by aligned, flattened, aphanitic, non-vesiculated, porphyritic fragments is diagnostic of weakly welded zones within otherwise massive weathering ash-flow sheets.

Beds of interspersed air-fall tuff constitute a minor porportion of unit 1B. However, immediately west of Dedeeya Creek, approximately 140 metres of crudely bedded crystal lapilli tuff and block breccia, underlie the main welded ash-flow sheet. The contact between these deposits is sharp and well defined. North of Adoogacho Creek, a graded tuff section interpreted as a ground surge deposit, preceded the eruption of ash-flow tuffs. In detail, this deposit consists at the base of 1 metre of crossbedded crystal tuff overlain by 75 centimetres of thinly laminated dust tuff that grades upward through more than 50 metres of lapilli and block-sized pyroclastic flow debris.

**UNIT 2:** This is a lithologically diverse assemblage consisting of interbedded air-fall tuff, thin ash-flow sheets, and epiclastic and chemical sedimentary rocks. It is best exposed south of Adoogacho Creek where intraformational basal conglomerate disconformably overlies the irregular paleosurface of unit 1B. Lenses and beds of conglomerate that are 70 metres thick in depressions thin to 1 metre above positive relief features. The conglomerate is overlain by over 200 metres of well-layered dust tuff, crystal ash tuff, and lesser thin ash-flow sheets. The tuffs are composed of fine-grained plagioclase and biotite crystals and sparse lithic fragments in a purple, green, or brown ash matrix. The uppermost 50 metres of the section marks a transition from subaerial tuffs to a distinctive succession of limestone or marl interbedded with recessive-weathering crystal ash tuff, siltstone, and fine-grained volcanic sandstone. Typical outcrops of limestone are laminated to thinly bedded; they weather to a dark to pale grey colour and contain abundant black siliceous laminations.

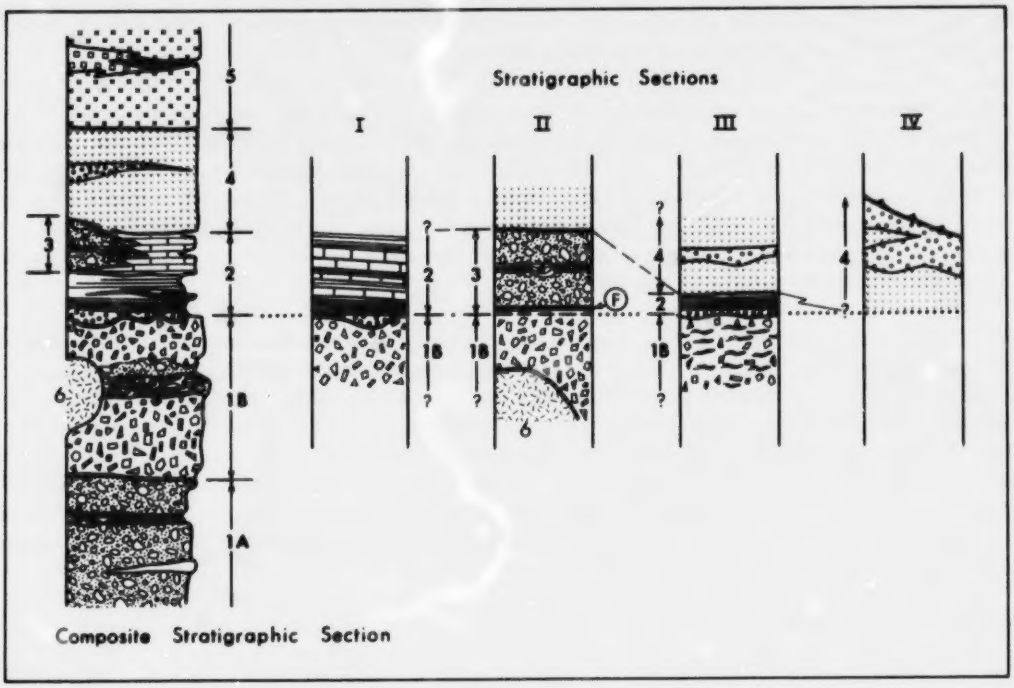
**UNIT 3:** These rocks are exposed as a flat-lying succession that overlies unit 1B. The unit consists of air-fall tuffs intercalated with volcaniclastic sedimentary rocks. The basal section of unit 3 comprises 10 metres of interbedded crystal dust tuff, mudstone, and fine-grained sandstone. At one locality south of Adoogacho Creek rare fossilized plant stems occur at the interface between mudstone and sandstone. This basal section is overlain by more than 150 metres of crudely bedded, poorly indurated lapilli block tuff. The rock contains round, monolithic, porphyritic, volcanic fragments in a pale green, feldspathic matrix containing sparse quartz phenocrysts.

The basal unit and overlying succession at first glance appear to record a continuous explosive cycle. However, detailed mapping suggests that the two lithologically similar tuff deposits are separated by an erosional break. The base of the upper volcanic cycle is recognized by the presence of a green, graded crystal dust tuff bed 2 metres thick, that forms a resistant stratigraphic marker within unit 3.

**UNIT 4:** Unit 4 is composed of trachyandesitic lava flows, comagmatic intrusive rocks, and local intraformational conglomerate. Near Tuff Peak, and south of Adoogacho Creek, unit 4 appears to be interdigitated with either units 1B, 2, and/or 3. The flows form massive, jointed outcrops with homogeneous composition containing plagioclase, augite, subordinate biotite, and apatite in an aphanitic, grey-green matrix. Quartz is absent or exceedingly rare, but sparse potassium feldspar megacrysts up to 1.5 centimetres in size serve to distinguish trachyandesite from the more widespread andesitic lava flows.

East of Tuff Peak and Dedeeya Creek volcanic conglomerate occurs as beds and lenses up to 80 metres thick between lava flows in unit 4. From a distance conglomerate has a chaotic appearance but closer inspection reveals crude internal bedding, grading, and laminated mudstone and sandstone beds. Clasts consist of rounded cobbles and boulders derived from underlying unit 4 flows.

**UNIT 5:** This map unit is well exposed on Metsantan Mountain where it overlies unit 4. The unit consists of massive-weathering flows with subordinate interfingered air-fall pyroclastic rocks. Quartz phenocrysts, varying from 1 to 3 millimetres in size are chacteristic of unit 5 and distinguishes these flows from similar-



LEGEND (FIGURES 53 AND 54)

**CRETACEOUS/EARLY TERTIARY**

| | |
|---|---|
| K/T | POLYMICTIC CONGLOMERATE, SILTSTONE, SANDSTONE, LIMESTONE, AND MINOR BASALT FLOWS |

**LOWER JURASSIC**

**TOODOGGONE VOLCANIC ROCKS**

| | |
|---|---|
| 5 | QUARTZ-ANDESITE LAVA FLOWS, MINOR CRYSTAL-DUST TUFF, CRYSTAL-LITHIC TUFF, AND SCARCE FOSSILIFEROUS SILTSTONE |
| 4 | PREDOMINANTLY ANDESITIC LAVA FLOWS AND HYPABYSSAL INTRUSIVE ROCKS, MINOR TRACHYANDESITE LAVA FLOWS, OLIGOMICTIC CONGLOMERATE WITH INTERCALATED MUDSTONE AND SANDSTONE |
| 3 | GREEN, CRYSTAL-LAPILLI TUFF, FELDSPATHIC CRYSTAL TUFF, CRYSTAL-DUST TUFF; MUDSTONE AND SANDSTONE CONTAINING FOSSILIZED PLANT FRAGMENTS |
| 2 | PURPLE, GREEN, AND BROWN DUST TUFF, CRYSTAL-LAPILLI TUFF, AND MINOR ASH FLOW SHEETS; INTERBEDDED LIMESTONE, MARL, CHERT, SILTSTONE, SANDSTONE, AND OLIGOMICTIC CONGLOMERATE |
| 1B | PINK OR RED-WEATHERING ASH FLOW SHEETS INTERDIGITATED WITH AIR FALL CRYSTAL-LITHIC TUFF AND TUFF BRECCIA |

**LOWER JURASSIC** *(CONTINUED)*

**TOODOGGONE VOLCANIC ROCKS** *(CONTINUED)*

| | |
|---|---|
| 1A | GREEN, MAUVE, OR BROWN CRYSTAL-LAPILLI TUFF, BLOCK BRECCIA, AND CRYSTAL-DUST TUFF; MINOR ASH FLOW SHEETS |

**TRIASSIC**

| | |
|---|---|
| TR | TAKLA GROUP: DARK GREEN, PURPLE, PYROXENE, PLAGIOCLASE MEGACRYST AND AMYGDALOIDAL BASALT LAVA FLOWS; ANDESITE LAVA FLOWS AND HYPABYSSAL INTRUSIVE ROCKS, LAPILLI TUFF AND BLOCK BRECCIA |

**INTRUSIVE ROCKS**

| | |
|---|---|
| 6 | PYROXENE BASALT WITH DIORITIC PHASES |

**SYMBOLS**

GEOLOGIC CONTACTS, DASHED WHERE INFERRED ..... ——– –

FAULTS, DASHED WHERE APPROXIMATE ........ ━━ ━ ━

THRUST FAULT, ASSUMED ....... ▲ ▲

AREA COVERED BY ALLUVIUM, COLLUVIUM, OR VEGETATION ....

PLANT FOSSIL LOCALITY .............. Ⓕ

STRATIGRAPHIC SECTION ......... I II III IV

Figure 54. Generalized stratigraphic sections, Toodoggone River—Chukachida River area.

appearing flow rocks of unit 4. The air-fall pyroclastic rocks locally form well-bedded deposits of green or purple crystal dust tuff and lapilli tuff. Unit 5 was deposited in a predominantly subaerial setting although subaqueous conditions existed locally as evidenced by ripple marks, scour features, and rare fossilized plant fragments found within thin, discontinuous mudstone and siltstone interbeds.

## STRATIGRAPHIC CORRELATIONS

The five map units identified north of the Toodoggone River are only partially correlative with the lithologic units established by Panteleyev (1983) in the immediately adjoining area south of the Toodoggone River. Panteleyev's readily identifiable 'grey dacite' ash flow that forms a widespread marker unit south of Finlay River is absent or lacks a recognized facies equivalent within this surveyed area. The trachyandesite flows of map unit 4 with their distinctive potassium feldspar megacrysts constitute part of Panteleyev's 1983 map unit 5. The massive andesitic lava flows of map unit 5 overlie trachyandesite of map unit 4 north of Metsantan Mountain. They are shown as a separate map unit (unit 5) in this study but are included in Panteleyev's andesite-trachyandesite unit 5.

## INTRUSIVE ROCKS

Intrusive rocks in the surveyed area include stocks of basaltic composition, and feldspar porphyry and andesitic dykes. One of the larger pyroxene basalt stocks intrudes unit 1B east of Adoogacho Creek. The basalt contains fresh, subhedral pyroxene phenocrysts on average 3 millimetres in diameter along with randomly oriented plagioclase microlites in a dark green, fine-grained matrix. Diorite, comprising medium-grained interlocking plagioclase, hornblende, and biotite crystals, forms a shallow embayment in the northeast contact of the stock. The origin of the diorite is uncertain, but its similar mineralogy and intimate association with the basalt suggests that the rocks may be comagmatic.

Subparallel, feldspar porphyry dykes trending 110 degrees to 150 degrees azimuth intrude both Toodoggone and Takla rocks in several places east of Moosehorn Creek. These dykes form distinctive, resistant, salmon-pink-weathering outcrops. They contain plagioclase, chloritized hornblende, biotite, and sparse quartz phenocrysts in a pink-coloured aphanitic matrix.

On Alberts Hump relatively fresh feldspar porphyry dykes dissect intensely altered tuffs and flows of map unit 5, demonstrating that the dykes postdate hydrothermal alteration. The hydrothermally altered rocks, consisting of a mixture of alunite, dickite, and quartz, have yielded a potassium/argon date of 190±7 Ma (Schroeter, 1982). Similar dykes also intrude altered volcanic rocks in the Cloud Creek area (Diakow, 1983). South of the Toodoogone River, feldspar porphyry dykes intrude both Takla and Toodoggone volcanic rocks near Baker mine and Hazelton volcanic rocks east of Saunders Creek. Deep-seated fractures with district-wide extent are postulated to be the principal structural controls for these intrusions. Vertical northwest-trending, andesitic dykes crosscut feldspar porphyry dykes north and south of Toodoggone River. Characteristically, these dykes form recessive outcrops averaging 1 to 2 metres wide. They are dark green and have a fine-grained texture; amygdules are calcite filled.

## STRUCTURE

The contact between Toodoggone and Takla volcanic rocks has an arcuate trace along the north-northeastern periphery of the map (*see* Fig. 53). In two localities along the contact, Takla rocks appear to overlie Toodoggone rocks, implying a thrust fault relationship. Further west, a network of steep northwest and east-west-trending faults cuts this contact and juxtaposes unit 1 against Takla rocks.

Bedding measurements derived from layered epiclastic rocks, tuff, and alignment of flattened clasts in ash-flow tuffs indicate that all map units dip 25 degrees or less toward the south-southwest. Locally, beds are steeper where stratigraphy is disrupted near intrusions or block faults.

## DISCUSSION

Five major map units have been identified north of the Toodoggone River. The succession is predominately andesitic in composition and is composed of subaerial lava flows, ash-flow tuffs, and pyroclastic fall deposits. Interruptions in volcanism during tectonism resulted in periodic erosion and reworking of volcanic members to produce conglomerate and finer grained clastic interbeds. Locally, depressions were inundated by marine waters. Short-term tectonic stability during waning volcanic activity promoted the deposition of tuffaceous carbonate rocks, fine-grained clastic rocks, and siliceous tuffs in some areas flanking the subaerial deposits.

The map units are interpreted to be successively younger through units 1 to 5 and appear to have been erupted without major pauses in volcanic activity. It is probable that structurally controlled linear vent systems were connected at depth to a common magma source. Collectively the volcanic succession records a reduction in the magnitude of pyroclastic erruptions with time. Unit 1 is interpreted to represent an early major eruptive stage in the area that produced widespread ash-flow sheets and air-fall deposits. The intermediate stage is characterized by sporadic volcanic activity and is exemplified by the well-layered succession of coarse tuffs in unit 3. These rocks are temporal and lateral equivalents to dust tuffs that contain limestone beds in unit 2. The final stage is marked by major lava flow eruptions of units 4 and 5.

## ACKNOWLEDGMENTS

The author gratefully acknowledges the courtesy and support from the following companies who, on occasion, provided transportation and lodging during the recent field season: DuPont of Canada Exploration Limited, Kidd Creek Mines Ltd., Newmont Exploration of Canada Limited, and SEREM Inc. Sincere thanks are extended to those individuals who kindly liberated time to guide tours and openly discussed their ideas and shared geologic information with the writer. They include: J. Clarke, B. Downing, T. Drown, C. Kowall, J. Laird, M. Morris, J. Paxton, M. Stammers, I. Sutherland, P. Tegart, M. Vulimiri, and D. Visagie. The writer benefited from the advice and guidance offered throughout this project by Dr. A. Panteleyev and Dr. R. W. Hodder. Furthermore, progress in collecting field data was enhanced significantly by the enthusiastic and capable assistance of Geoff Goodall and Mike Fournier.

Central Mountain Air Services Limited and Airlift Corporation provided safe, reliable air service. Joyce Warren in Smithers fulfilled all expediting requests in a prompt, reliable manner.

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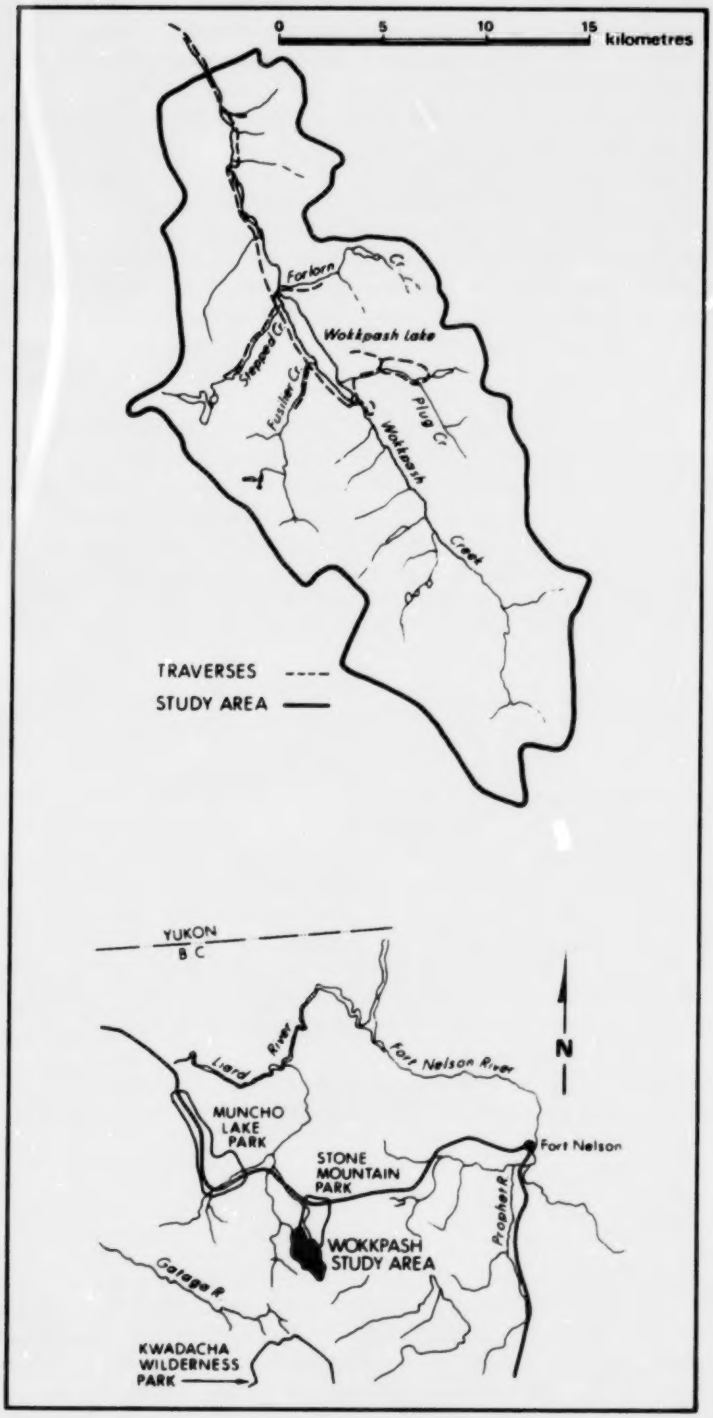


Figure 55. Location map with foot traverses shown: Wokkpash Park Proposal Area.

# GEOLOGIC RECONNAISSANCE OF THE WOKKPASH PARK PROPOSAL AREA (94K)

By A. Legun

A mineral potential reconnaissance of the Wokkpash Park Proposal Area was conducted. The area, which encloses the watershed of Wokkpash Creek, is located 32 kilometres due south of Mile 400 on the Alaska Highway (Fig. 55). Access is by the Racing River road, which eventually ends at the site of the former Churchill Copper mine. A trail enters the Wokkpash Valley near the road's intersection with Wokkpash Creek.

Wokkpash Creek and its tributaries were examined by air and on foot. Traversed tributaries include Plug, Fusilier, Stepped, Forlorn, and several unnamed creeks. The area south of Wokkpash Lake and high ground of the drainage divide encompassing the valley were not examined on foot due to access problems and time contraints.

Rock exposure is very good except in the main valley which has a glacial fill. Rocks were examined for evidence of the following types of regional mineralization:

(1) Lead-zinc in breccias of Devonian limestone (Robb Lake type).
(2) Disseminated copper in Proterozoic quartzites.
(3) Copper veins associated with gabbroic dykes that cut Proterozoic rocks (Churchill mine type).
(4) Copper in Ordovician limestones and sandstones of the Ketchika Group.

Devonian limestones and Proterozoic quartzites were examined at several locales but it was not possible to check dyke contacts or Ordovician limestones because these rocks are restricted to small areas in remote and rugged locations.

The regional geologic map of Taylor and Stott (1973) was used as a stratigraphic guide. On a local scale some map unit boundaries are incorrectly positioned on the map. For example, Proterozoic quartzites underlie Plug Creek and the Proterozoic/Paleozoic contact, which is marked by a quartzite fragment regolith, is exposed on Fusilier Creek; only Paleozoic carbonate units are indicated on Taylor and Stott's map.

No metallic mineral showings were found. Agmatitic breccias occur in Devonian limestones in Forlorn gorge and Stepped Creek but barren calcite comprises the entire breccia matrix. No galena and sphalerite were found and fluorite was noted only once. Proterozoic quartzites are often rusty weathering but only disseminated pyrite was noted on fresh surfaces; there was no hint of copper. Analyses of these and other rocks of interest are given in the accompanying table.

**ANALYTICAL RESULTS FOR SELECTED ROCK SPECIMENS**
**FROM THE WOKKPASH PARK PROPOSAL AREA**
**(94K)**

| LOCATION | FORMATION | ROCK TYPE | Au *ppm* | Ag *ppm* | Cu *ppm* | Pb *ppm* | Zn *ppm* | Co *ppm* | Ni *ppm* | Mo *ppm* |
|---|---|---|---|---|---|---|---|---|---|---|
| Upper Wokkpash Creek | Tuchodi | quartzite | — | — | 50 | 12 | 110 | 2 | 13 | <3 |
| Plug Creek | ? | pyritic shale | — | — | 27 | 11 | 8 | 3 | 14 | <3 |
| Fusilier Creek | Proterozoic/ Paleozoic contact | quartzite breccia to conglomerate (regolith) | <0.3 | <10 | — | — | — | — | — | — |
| Stepped Creek | Stone/Dunedin | breccia | — | — | 26 | 5 | 6 | <2 | 6 | <3 |

Rocks of the proposal area are dominantly clean platformal carbonates and quartzites; there is little evidence of subsequent alteration. The area does, however, display a striking interplay of geology and scenery (Plate VII). Erosion developed hoodoos in glacial fill that line Wokkpash gorge in soldierly fashion for several kilometres. They are impressive in terms of number, size, and 'gravity defying' suspended boulders. Forlorn gorge is very narrow, only 10 to 20 metres wide at the base, but a very deeply incised canyon in limestone; it is reminiscent of Maligne canyon in Jasper Park. The canyon is accessible for at least half its length because the creek gradient is surprisingly low. On the upper levels of Stepped Creek, a creek disappears at the thrust contact between Proterozoic quartzites and Paleozoic carbonates. Apparently during early summer meltwater flow reaches and fills a downstream depression or sink hole and forms a shallow lake that is visible on air photographs. By late summer, lake waters have drained underground through one or more 'swallow holes'. This drainge apparently emerges as springs in a permanent lake that is down valley; it has considerable outflow volume but no surface inflow.

In conclusion, no mineral showings were found during a reconnaissance of several stratigraphic intervals of interest in the north half of the park proposal area. Striking hoodoos and a previously unknown disappearing lake and creek were discovered during the course of field studies.

Plate VII. Stepped Creek, Wokkpash Park Proposal Area.

# GEOLOGIC SETTING OF THE PRECIOUS METAL DEPOSITS IN THE STEWART AREA

## (104B/1)

By D. J. Alldrick

## INTRODUCTION

The British Columbia Ministry of Energy, Mines and Petroleum Resources investigated regional geology and mineral deposits of the Stewart area during 1964 and 1965 (Grove, 1971). The opening of Scottie Gold mine, recognition of an epithermal precious metals camp in similar volcanic rocks of the Toodoggone River area, and newly discovered stratabound precious metal mineralization in the Big Missouri mine area created incentives to study the area in more detail.

The objectives of this project are:

(1) Document structural and stratigraphic relationships of the host volcanic sequence and its contact relationships with adjacent terranes.

(2) Determine the evolution and depositional environment of the volcanic system from petrographic and geochemical studies of the sequence.

(3) Characterize the structural, stratigraphic, mineralogical, and trace element contents of precious metal and base metal deposits of the area.

(4) Conduct metallogenic studies and define areas of high mineral potential.

(5) Sample host rocks and ore zones for fossil and radiometric dating and compare them with other volcanic terranes around the Middle Jurassic Bowser basin.

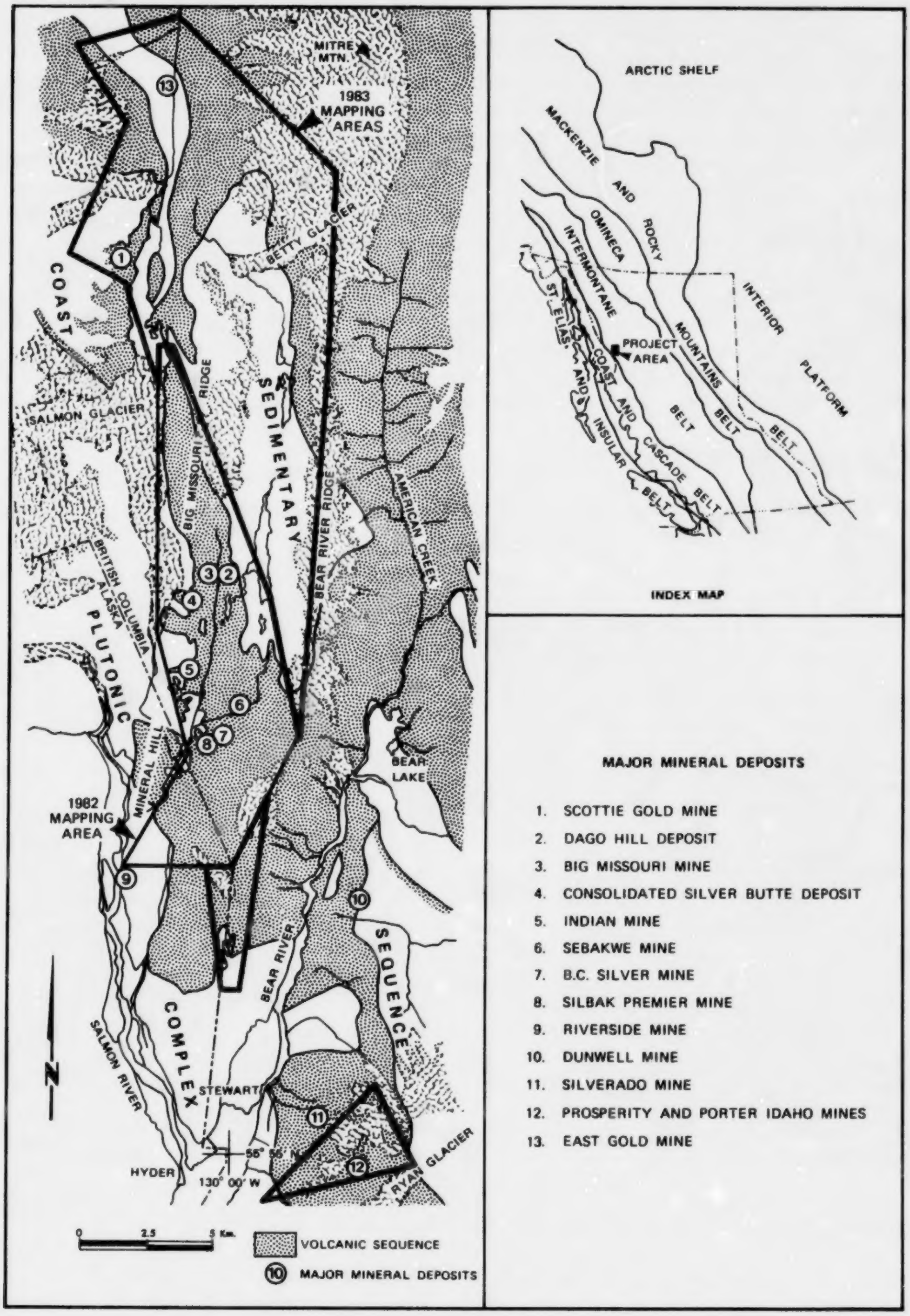
The report summarizes preliminary results of the first three objectives.

## HISTORY AND PREVIOUS WORK

Prospectors began to explore the Stewart area in 1898 enroute to the Klondike. No major placer gold deposits were found but mineralized float led to the discovery of gold-quartz vein deposits. Continued prospecting located the gossan at Silbak Premier mine in 1910. Subsequently, the Stewart camp became the third greatest lode-gold-producing area in British Columbia. Between 1918 and 1968 Silbak Premier mine production alone totalled 4.3 million tonnes grading 13 grams gold per tonne and 298 grams silver per tonne. Tipper and Richards (1976) outlined the tectonic evolution of the region. Major geological reports of the Stewart area by Grove (1971) and the Big Missouri camp by Galley (1981) include historical reviews of geological studies in the area and extensive bibliographies. Barr (1980) provides a concise geological review of the Silbak Premier mining camp. A compilation of recent mapping and Ministry work is shown on Figures 56 and 57.

## REGIONAL GEOLOGY

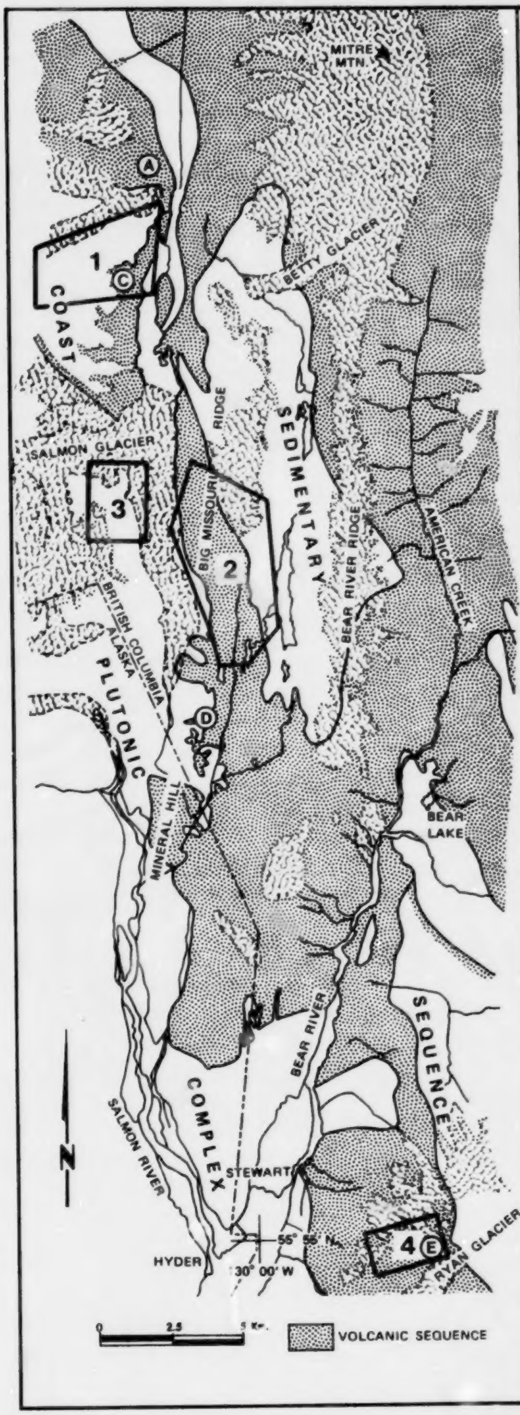
The study area is underlain by a north-northwest-trending belt of folded volcanic rocks (shaded on Fig. 56) which contains a thick sedimentary sequence infolded along a synclinal axis. The volcanic and sedimentary rocks are intruded by small stocks and extensive dyke swarms. The volcanic rocks are bounded on the west by composite stocks and batholiths of the Coast Plutonic Complex.



MAJOR MINERAL DEPOSITS

1. SCOTTIE GOLD MINE
2. DAGO HILL DEPOSIT
3. BIG MISSOURI MINE
4. CONSOLIDATED SILVER BUTTE DEPOSIT
5. INDIAN MINE
6. SEBAKWE MINE
7. B.C. SILVER MINE
8. SILBAK PREMIER MINE
9. RIVERSIDE MINE
10. DUNWELL MINE
11. SILVERADO MINE
12. PROSPERITY AND PORTER IDAHO MINES
13. EAST GOLD MINE

Figure 56. Regional geology and mineral deposits, Stewart area.



**RECENT GEOLOGIC STUDIES USED FOR COMPILATION**

1. WARES AND GEWARGIS, 1982
2. GALLEY, 1981
3. KLEPAKI, 1982
4. GREIG AND KENYON, 1982

**MAJOR EXPLORATION PROGRAMS**
**(1983)**

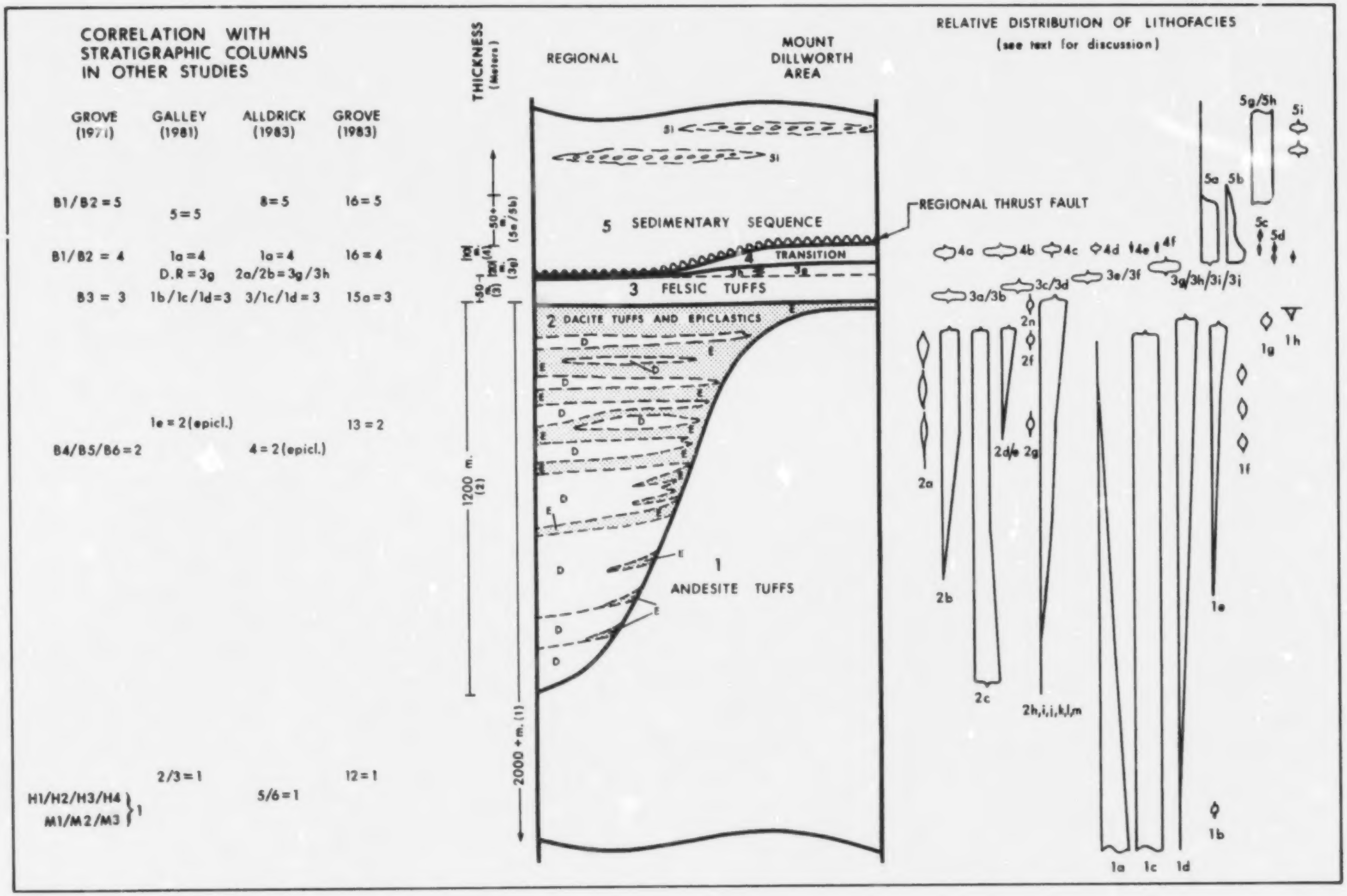
TIDE MOUNTAIN AREA
(NORTHAIR GROUP)
GRANDUC MILLSITE AREA
(CANADA WIDE MINES)
SCOTTIE GOLD PROPERTY
(SCOTTIE GOLD MINES)
BIG MISSOURI CAMP
(WESTMIN RESOURCES)
CONSOLIDATED SILVER BUTTE
(ESSO MINERALS)
PREMIER MINE AREA
(WESTMIN RESOURCES)
HIGH ORE PROSPECT/WOODBINE PROSPECT
(ESSO MINERALS)
STONER PROSPECT
(EXXON MINERALS)
MINERAL HILL
(GREENWICH RESOURCES)
BAYVIEW MINE
(KINGDOM RESOURCES)
PROSPERITY/PORTER IDAHO
(PACIFIC CASSIAR)

**NEW MINERAL DISCOVERIES**
**(1982 – 1983)**

A TIDE MOUNTAIN VEINS
(NORTHAIR GROUP)

C 'O' ORE ZONE
(SCOTTIE GOLD MINES)
D CONSOLIDATED SILVER BUTTE
(ESSO MINERALS)
E 'D' VEIN EXTENSION
(PACIFIC CASSIAR)

Figure 57. Recent geological studies, Stewart area.



CORRELATION WITH STRATIGRAPHIC COLUMNS IN OTHER STUDIES

| GROVE (1971) | GALLEY (1981) | ALLDRICK (1983) | GROVE (1983) |
|---|---|---|---|
| B1/B2 = 5 | 5=5 | 8=5 | 16=5 |
| B1/B2 = 4 | 1a=4<br>D.R = 3g | 1a=4<br>2a/2b=3g/3h | 16=4 |
| B3 = 3 | 1b/1c/1d=3 | 3/1c/1d = 3 | 15a=3 |
| B4/B5/B6=2 | 1e = 2(epicl.) | 4 = 2(epicl.) | 13 = 2 |
| H1/H2/H3/H4 } M1/M2/M3 } 1 | 2/3=1 | 5/6=1 | 12=1 |

Figure 58. Stratigraphic column for Salmon River map-area.

The volcanic and sedimentary rocks of the Stewart area have been mapped by Hanson (1935) and Grove (1971, 1973, and 1983) as Hazelton Group strata of Early Jurassic to Middle Jurassic age. They are considered to be correlative with the type Hazelton area 200 kilometres to the southeast.

The rocks correlate remarkably well with the Hazelton section described by MacIntyre (1976, pp. 11-19) in the Tahtsa Lake area to the south. Tentative correlation can also be made with the lower part of the Hazelton section as outlined by Duffell (1959) in the Terrace area.

Correlations with other sections elsewhere described as Hazelton Group by Duffell and Souther (1965), Tipper (1971), and Tipper and Richards (1976) cannot be made on a lithological and stratigraphic basis. Similarly map sections presented by Carter and Kirkham (1969) and Carter (1973) do not correlate with Stewart stratigraphy. However, Grove (1973) presents fossil evidence for correlation of the Stewart stratigraphy on the basis of age with other Lower to Middle Jurassic volcanic sections. Grove's Nass Formation (1983) of the upper Hazelton Group is an alternative name for the Bowser Lake Group described by Tipper and Richards (1976).

## VOLCANIC STRATIGRAPHY

Volcanic map units in most of the Salmon River valley strike north-northwest and generally dip vertically to steeply eastward. The volcanic pile is predominantly composed of massive, green andesitic tuffs which rarely show bedding features or indications of stratigraphic top. Grove (1971) discusses the extensive alteration zones that occur around many of the mineral deposits. This pervasive alteration tends to obscure primary bedding and textural features.

In 1982, Alldrick (1983) determined the direction of stratigraphic tops based on graded beds in felsic pyroclastic rocks and on variations in composition of tuff breccia fragments. Mapping during 1983 located waterlain units with distinct tops indications in all major stratigraphic subdivisions except map unit 4. The consistent tops direction was to the east, confirming the major stratigraphic divisions and major structures established by Grove (1971, 1983). Figure 58 illustrates the stratigraphic column and compares terminology used in the Stewart area by other workers.

**MAP UNIT 1:** Map unit 1 is composed of a thick succession of green, greyish green and greenish grey andesitic tuffs. Lesser red, maroon, purple, and black tuffaceous units are intercalated with these beds at irregular intervals. Textures vary from medium to coarse ash tuffs through lapilli tuffs to coarse tuff breccias. Crystal and crystal-lithic tuff units containing white feldspar and/or hornblende phenocrysts are the most common lithology. A distinctive unit of crystal tuff containing bimodal feldspar phenocrysts outcrops on 49 Ridge on the west side of Mount Dillworth. In this unit the smaller (3 to 5-millimetre) grains are subhedral to euhedral white crystals while the larger grains (1 to 3 centimetres) are buff-coloured, inclusion-rich euhedral crystals.

Thin waterlain green tuffaceous beds have been located on Mount Welker, on 'Tide Mountain', and on the ridge west of the Scottie Gold mine. The beds are about 10 centimetres thick and up to four beds may occur together. Many beds show grading which indicates tops towards the synclinal axis on Mount Dillworth (Fig. 59). No other waterlain or submarine textures have been noted in the andesite sequence during recent mapping and the entire sequence is, therefore, interpreted to be subaerial – predominantly tuffaceous units with some intercalated andesite flows.

The red/maroon tuffaceous units are thin (≤5 metres) feldspar crystal tuff beds which may represent time-stratigraphic horizons of alteration rather than stratigraphic units. They do not have regional extent

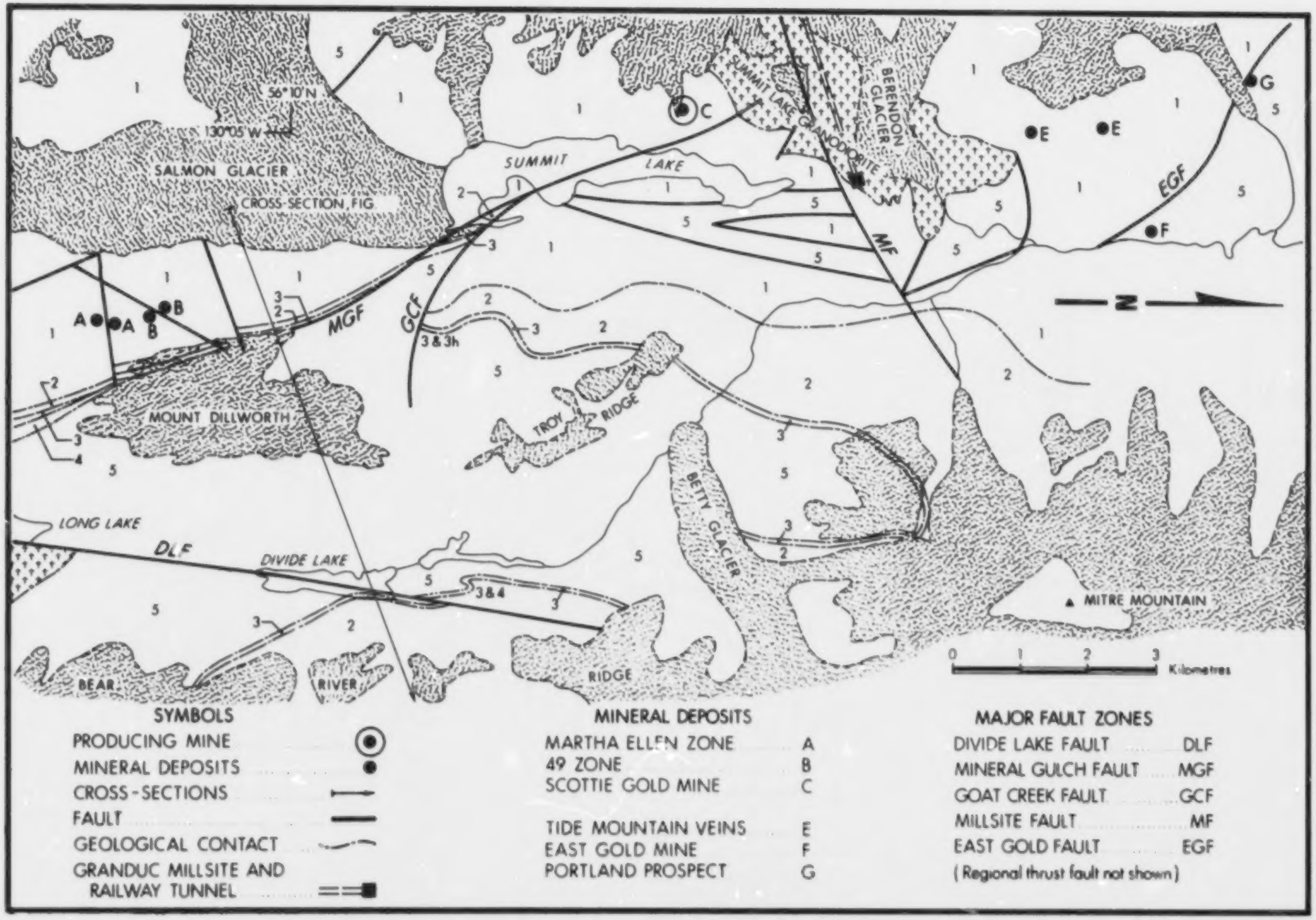


Figure 59. Geology and mineral deposits of the northern Salmon River valley.

but do provide useful markers on a property scale and were an exploration/mining control at the Silbak Premier mine (Langille, 1945). McGuigan has suggested (personal communication, 1983) that these distinctive zones could represent paleosurfaces during development of epithermal systems.

Regional correlation of individual tuff beds within the andesite sequence of map unit 1 has not been possible, but a general pattern of textural zoning within the sequence has been recognized and is illustrated on Figure 58. Medium to coarse ash tuffs (1a) are most abundant in the lower part of the sequence along with the thin waterlain tuffs (1b). Lapilli tuffs (1c) are uniformly distributed but crystal tuffs (1d) and crystal-lithic tuffs are somewhat more abundant upward in the sequence. The medium tuff breccias (1e) and red/maroon crystal tuffs (1f) occur only in the upper half of the sequence. Coarse tuff breccias (1g) and the bimodal crystal tuffs (1h) are known only at the top of the sequence in the Mount Dillworth area.

The base of the andesite volcanic sequence has not been identified but the overall thickness is at least 1 500 to 2 000 metres in the Scottie Gold mine area.

**MAP UNIT 2:** Map unit 2 is a complex succession of interbedded tuffs and fine to coarse epiclastic sedimentary rocks. The sequence is 1 200 metres thick on the west slope of Mitre Mountain; it thins southward until it nearly wedges out between Mineral Gulch and Monitor Lake and thickens southeastward in the area of Bear River Ridge at Mount Shorty Stevenson (Fig. 59). As a generalization, this map unit consists predominantly of a thick dacitic (?) tuffaceous unit near the base with occasional intercalated epiclastic beds that pass upward into interbedded dacitic tuffaceous and epiclastic units. These are overlain by a thick sequence of epiclastic beds with rare dacitic tuffaceous interbeds. Local white limestone beds (2g) crop out on the west side of Mitre Mountain about midway in the sequence and a distinctive porphyritic dacite (?) flow (2f) crops out within the upper epiclastic beds on Bear River Ridge east of Divide Lake.

The depositional environment is interpreted to be predominantly subaerial although the epiclastic beds exhibit waterlain textures such as grading, crossbedding, and scouring. These show consistent stratigraphic tops towards the synclinal axis on Mount Dillworth.

The dacitic (?) tuffs range in colour and texture from pale waxy yellow or yellow-green crystal tuffs (2c) and welded tuffs (2d) to pale green coarse ash tuffs (2b) and dust tuffs (2a). Although the tuffs are interbedded with waterlain epiclastic sediments, no distinct waterlain tuffaceous textures have been noted. Crystal tuffs with medium-grained (0.5 to 1.0-centimetre) white subhedral to euhedral feldspar phenocrysts are abundant. No hornblende phenocrysts have been noted but rare fine-grained (≤5-millimetre) quartz crystals have been identified in some samples.

Tuffs are massive but crystal tuffs commonly show a crude banding consisting of crystal-rich bands 1 centimetre to 2 centimetres apart separated by crystal-poor bands of fine-grained ash. Relatively thick units (10 metres or more) of this banded rock have been noted on Troy Ridge, Bear River Ridge, and Mount Rainey. Banding possibly developed during repeated eruptions of combined ash and crystals, with each eruption undergoing partial sorting during air fall.

Dacitic welded tuffs (2d) exhibit eutaxitic textures with flattened fiamme of various sizes up to 12 centimetres long.

An unusual, thinly banded or layered dacitic rock (2e) has been identified on Bear River Ridge and locally on Mount Rainey. The rock is yellowish grey in colour and consists of interlayered 1.0 to 2.0-centimetre-thick bands of yellowish coarse ash and ~0.5-centimetre-thick grey siliceous layers. The siliceous layers are undulatory and individual layers can be traced for at least 2 metres. The texture might possibly form by flattening and welding of layers of fine lapilli-sized pumice fragments that are interbedded with layers of ash.

A distinctive porphyritic, dacitic volcanic flow (2f) crops out on the crest and west shoulder of Bear River Ridge east of Divide Lake. The matrix consists of massive, aphanitic, siliceous, pale grey dacite or rhyodacite with 5 to 10 per cent scattered coarse white feldspar phenocrysts and phenocryst aggregates. The phenocrysts are up to 1 centimetre long and some of the aggregate masses are up to 4 centimetres in diameter. All phenocrysts have been partially digested leaving irregular rounded remnants on which crystal faces are rarely preserved. The resulting texture is similar to the 'flower porphyry' and 'snowflake porphyry' rocks that occur elsewhere in British Columbia.

The epiclastic units have distinctive bedding, textures, and colouring that make them readily recognizable. The matrix of these sedimentary rocks is typically brick-red to maroon to purple, although some cream, buff, and olive-green units were noted. Rounded cobbles of volcanic rock within these beds range in colour from red to purple, green, and grey. Exposures are common in which monolithic cobbles (2k) are identical in colour to the matrix but striking exposures of multicoloured heterolithic boulder conglomerates (2l) are widespread. Textures range from siltstones (2h) through sandstones (2i) and grits (2j) up to coarse boulder conglomerates (2m). Conglomerates are characteristically matrix supported but one clast supported, coarse boulder conglomerate bed (2n) with boulders up to 0.5 metre in diameter was noted on the east face of 49 Ridge.

Bedded epiclastic units locally display graded beds, crossbedding, and scour and fill channels that allow tops determinations. These features consistently show tops towards the synclinal axis on Mount Dillworth. Cobbles in the epiclastic beds are composed of the andesitic and dacitic lithologies described previously; no clasts of rhyolitic volcanic material have been identified. The epiclastic beds predominate at the top of the interbedded dacitic volcanic/epiclastic sequence of map unit 2 and have a sharp upper contact with the overlying felsic volcanic sequence (map unit 3).

**MAP UNIT 3:** Map unit 3 is a widespread relatively thin (±50-metre) succession of 20 centimetre to 25-metre-thick felsic volcanic tuffaceous and pyroclastic beds. The map unit is thicker along the western edge of Mount Dillworth north to Summit Lake. The rocks appear to be highly siliceous and are probably rhyolitic in composition. Galley (1981) shows whole rock analyses from felsic rocks near the Long Lake dam which are dacitic in composition.

The regional succession examined on Mitre Mountain, at Divide Lake, and on the west slope of Mount Shorty Stevenson is remarkably consistent. The lowermost bed is an aphanitic dust tuff (3a) which is typically pale olive-grey to grey but it grades laterally into a bright turquoise rock near Summit and Divide Lakes. This rock has been extensively altered to a bright maroon or purple colour (3b) and the alteration can be seen lensing in and out over short distances. This rock is normally massive but near the southeast corner of Summit Lake it contains fine (up to 4 millimetres) silica-filled vesicles and large euhedral pyrite cubes (up to 1 centimetre).

This dust tuff unit grades upward into a lapilli tuff (3c) which is variably welded (3d). The lapilli tuff locally contains fiamme but more commonly has angular pumice fragments (3c) as well as angular felsic volcanic lapilli.

The lapilli tuff, in turn, grades upward into a siliceous lapilli tuff or tuff breccia (3e). The clasts are heterolithic, laminated to massive, grey to white cherts and rhyolites or other pervasively silicified lithologies. This siliceous tuff breccia is the uppermost member of map unit 3 seen at Mitre Mountain and Mount Shorty Stevenson. In both areas this unit is 20 to 25 metres thick and is in fault contact with overlying black siltstones and slates. In the Mount Shorty Stevenson area the upper half of this unit is progressively darkened by carbon until the siliceous tuff breccia is medium grey to charcoal coloured (3f).

In the Troy Ridge, Mount Dillworth, Fetter Lake, Divide Lake, and Monitor Lake areas the uppermost lithology of map unit 3 is a chaotic rhyolitic ash flow tuff. It is highly pyritiic (3g) from the south end of Mount Dillworth to the Summit Lake area and contains heterolithic rounded cobbles and large angular lithic fragments. This rock contains 15 to 20 per cent very fine disseminated pyrite as well as large pods and minor lenses of massive fine-grained pyrite. Outcrops form resistant domes and ridges of brilliant red-orange, yellow, and red-brown colour along the west side of Mount Dillworth. On Troy Ridge and southward from Mount Dillworth similar ash flow textures can be identified, but the unit contains no pyrite (3h). No rounded cobbles have been noted in this distal facies of the rhyolite ash flow and the angular lithic fragments are lapilli size; it extends southeastward beyond Monitor Lake and northward along the west side of Troy Ridge but exact limits have not been defined. At the northeast corner of Divide Lake this unit is only 2 to 3 metres in thickness and contains small lapilli size angular fragments.

The coarse, chaotic, pyritic, boulder and cobble-rich facies (3g) of this rhyolitic ash flow is interpreted to be a near-vent facies, a relationship originally proposed by Galley (1981). However, an exposed dome or volcanic vent has not been located. On Troy Ridge and near Monitor Lake the distal facies (3h) of this ash flow contains minor impure, gritty, limestone lenses (3i). Between Mount Dillworth and Fetter Lake the distal facies is variably enriched in carbon and may be charcoal in colour (3j). The ash flow is either in fault contact with overlying black siltstones and slates of map unit 5 or in sharp conformable (?) contact with charcoal to black rocks of map unit 4, called the 'transition sequence'.

**MAP UNIT 4:** The 'transition sequence' consists of mixed charcoal to black interbedded tuffs (4a), fine-grained black crystal tuffs (4b), ash-rich argillaceous sedimentary rocks (4c), and minor amounts of gritty limestones (4d) and fossiliferous limestones (4e and 4f). This map unit is exposed intermittently due to faulting, talus cover from adjacent black siltstones and slates, or snow and ice cover on Mount Dillworth. Possibly locally it was not deposited. It has been identified in outcrops virtually everywhere that the underlying rhyolitic ash flow tuffs (3g, h, j) cap the felsic volcanic sequence of map unit 4. Therefore, this transition sequence is thought to be derived by mixing of varying proportions of fine, water-transported detritus with air fall ash and crystals from felsic pyroclastic activity during waning volcanism. These mixed sediments were deposited in an encroaching, carbon-rich marine environment.

The predominant rock type is a distinctive black to charcoal grey crystal tuff (4b) containing fine (<3-millimetre) white feldspar crystals; it is extensively exposed south and south-southeast of Monitor Lake and is visible in drill core left near the Lakeview workings. Other lithologies include black gritty coarse ash tuffs (4a) and black argillites and slates (4c) that are locally pyritic; they crop out along an old road running north from Fetter Lake. The black gritty coarse ash tuff (4a) is exposed at the southwest end of the penstock tunnel near the Long Lake Dam. Gritty, grey, weakly pyritic, fossiliferous limestone lenses and pods are exposed 100 metres north of the northern end of 49 Ridge (4e) and are also exposed a few hundred metres north of Divide Lake (4f). The upper contact of map unit 4 is always marked by a regional thrust fault.

**MAP UNIT 5:** The regional thrust fault puts rocks of map units 4 and 3 and, rarely, map unit 2 into contact with black carbonaceous siltstones and slates at the base of map unit 5.

The stratigraphy of these sedimentary rocks is described in Grove (1971); it has been examined only partly in the present study. The lower 50 to 100 metres of the sedimentary succession consists of black, thin to medium-bedded siltstones (5a) and shales (5b) with minor amounts of intercalated siliceous beds (5c) and limestones (5d) that are locally fossiliferous (5e and 5f). This sequence grades upward into medium grey greywackes (5g), sandstones (5h), and intraformational conglomerates (5i). The conglomerates consist of black siltstone slabs and cobbles in a grey sandstone matrix. The limestone lenses are regionally distributed but thin. The only two that are fossiliferous correlate well with fossiliferous limestones in map unit 4 on the other side of the thrust fault (Fig. 59). The slates and siltstones locally contain small amounts of disseminated pyrite. Local rounded pebbles and small cobbles occur in one exposure on Mount Dillworth. The sedimentary sequence is characterized by abundant scour and fill structures, grading, and crossbedding; tops are toward the axis of the Mount Dillworth syncline.

## STRUCTURE

**FOLDING:** The major structural feature in the area is the Mount Dillworth syncline; it trends north-northwest/south-southeast and is doubly plunging. The syncline deforms the stratigraphy described previously and the outcrop pattern now resembles a series of concentric rings. Vergence of minor folds that crop out north of Divide Lake and north of Daisy Lake support this structural interpretation. The hinge area of the major fold is exposed on Mitre Mountain and on the west slope of Mount Shorty Stevenson. Regional dips on the west side of the syncline are typically vertical but can range between 80 degrees west and 70 degrees east. The alternating thin-bedded siltstones and thicker, more massive greywackes and sandstones of map unit 5 are folded disharmonically (Grove, 1971, Plate XI). An idealized cross section of this structure is presented on Figure 60.

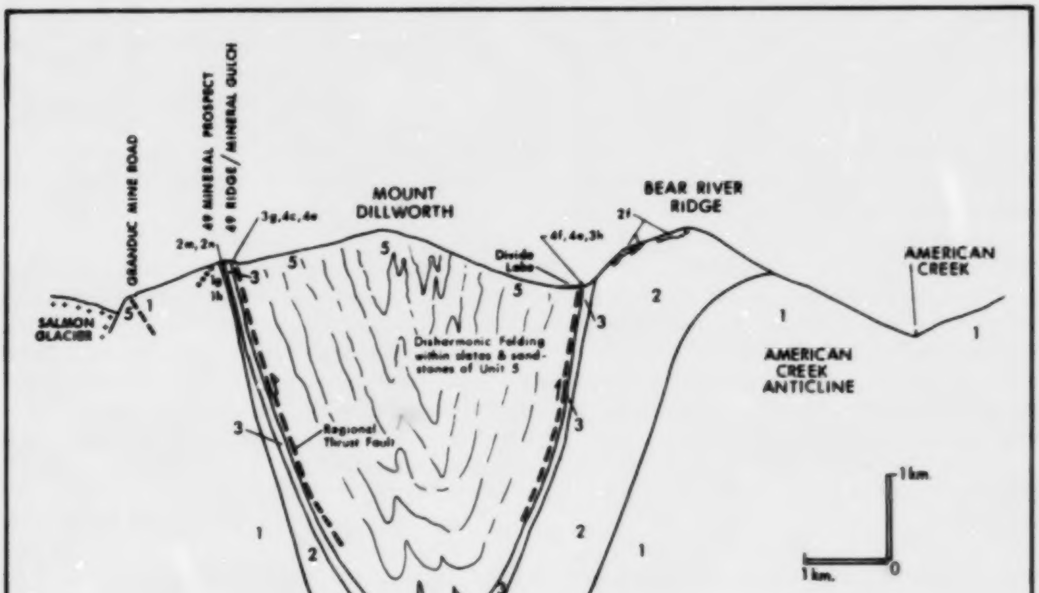


Figure 60. Geologic cross-section through Mount Dillworth (compare with Alldrick, 1983, Fig. 67).

**FAULTING:** A minor thrust fault that encircles the Dillworth syncline separates the sedimentary sequence from volcanic rocks of map units 4 and 3 and, locally, map unit 2. Volcanic rocks adjacent to this fault show little or no deformation but thin-bedded black slates and siltstones are chaotically deformed and cut by white quartz veinlets. The fault plane is characteristically marked by a 6 to 8-centimetre massive white quartz vein that locally swells up to 50 centimetres. Clayey fault gouge fills this fault plane in exposures near the east side of Summit Lake. In the Slate Mountain area it is filled with scattered, pea-sized, black siltstone pebbles in a matrix of massive white vein quartz. This distinctive rock has been called 'chert pebble congomerate'; it was interpreted to be the basal conglomerate unit of the sedimentary sequence. On the Lower Granduc road this fault places black siltstone beds on highly pyritic rhyolite ash flow tuff (3g) at the top of map unit 3. There the fault plane is 2 metres wide and filled with well-rounded siltstone pebbles up to 3 centimetres in diameter in a friable matrix of pyrite and black clay. Over most of the region the fault zone is not exposed.

Major and minor faults abound and present serious problems for regional and property scale exploration. Induced polarization geophysical surveys have been useful in tracing mineralized zones across major and minor fault dislocations. Some major faults are illustrated on Figures 59 and 60.

**PALEOTOPOGRAPHY:** The schematic section of Figure 61 uses the base of the rhyolitic ash flow as a time line datum. It is not a paleotopographic datum line but is probably a close approximation. Apparent paleorelief on the underlying andesitic volcanic unit is extreme. If chaotic felsic volcanic rocks in the Mount Dillworth area represent a near-vent sequence, the stratigraphy probably drapes downward to the north and south from the 'vent area'.

## METAMORPHISM

Galley (1981) identified greenschist facies metamorphic minerals in a petrographic study of the Big Missouri claim group. Interpretation is complicated by extensive alteration associated with the many mineral deposits in the area (Galley, 1981; Grove, 1971). Macroscopic examination of slabbed rocks suggests that the regional metamorphic grade is roughly the same intensity throughout the Salmon River area.

## MINERAL DEPOSITS

Detailed studies are underway on major mineral deposits at the Prosperity/Porter Idaho mine (Alldrick and Kenyon, this volume), Scottie Gold mine, Big Missouri mine area, and Silbak Premier mine. Most other prospects and mineral occurrences in the Salmon River valley have also been examined, including new precious metal discoveries of Scottie Gold Mines Ltd., Northair Group, Canada Wide Mines Ltd., Esso Minerals Canada Ltd., and Pacific Cassiar Limited.

This progress report briefly reviews the stratigraphic and structual setting of a few of the deposits, schematically plotted on Figure 61, and considers some of the constraints on genetic interpretation imposed by the regional geologic setting.

**SCOTTIE GOLD MINE:** The gold-silver ores of Scottie Gold mine occur as parallel veins of massive pyrrhotite and pyrrhotite-pyrite. These veins have associated base metal sulphide mineralization disseminated in envelopes of intense chlorite, and hematitic siliceous alteration. The three main veins in the mine, including the newly discovered O vein, lie in subparallel fault or shear zones that trend 110 degrees and dip 75 to 80 degrees north. Within these structures the ore veins plunge 65 to 70 degrees north-northwest. Several subparallel mineralized veins are exposed at surface north of the mine workings (Wares and

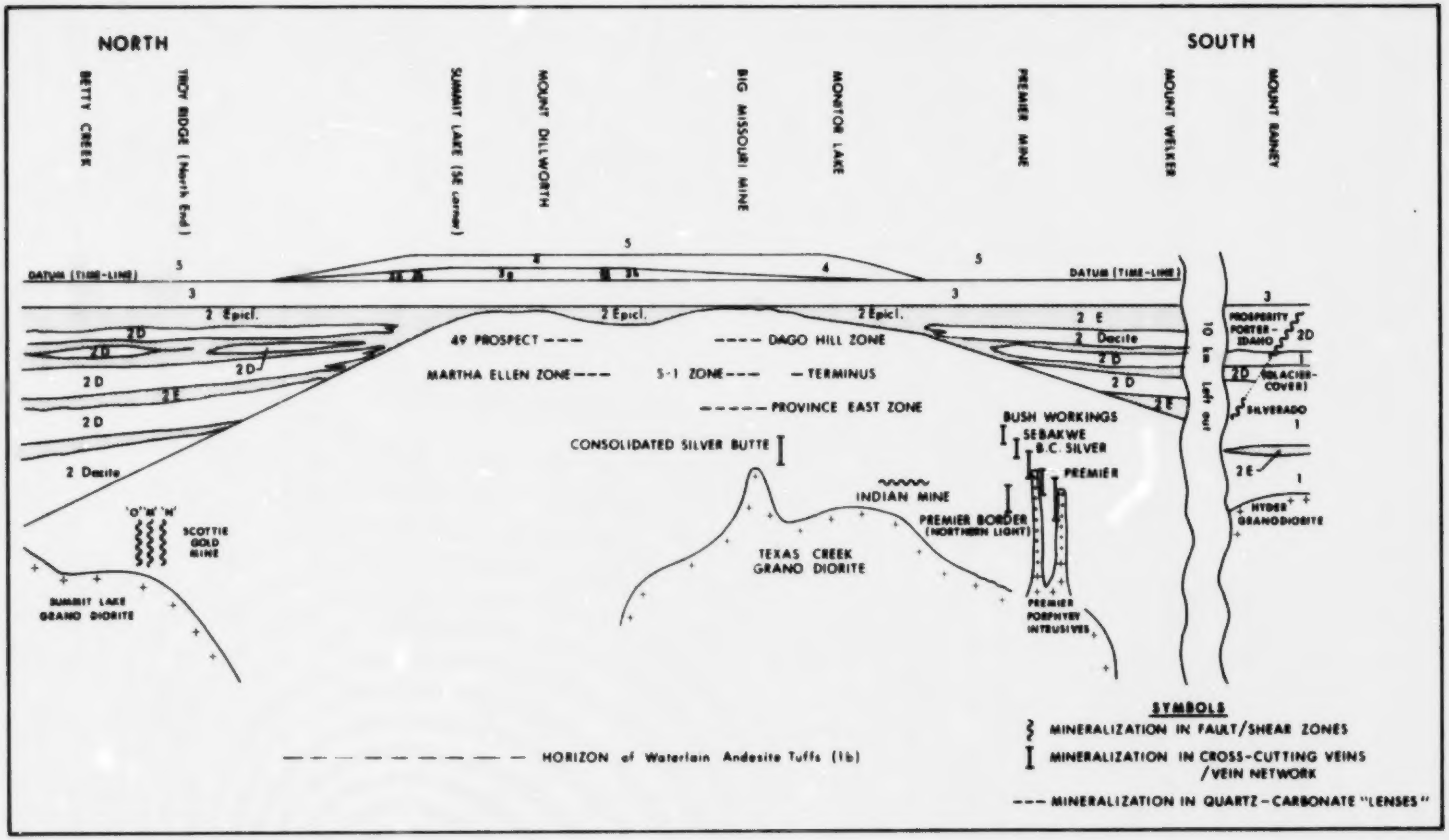


Figure 61. Schematic cross-section showing the stratigraphic position of mineral deposits, Salmon River area.

Gewargis, 1982). These surface showings were the focus of a major exploration program this summer. The ore structures cut host rock andesite lapilli tuff and tuff breccia which strike 135 degrees and dip 75 degrees northeast in the mine area.

The high-grade pyrrhotite veins have been interpreted as epigenetic mesothermal veins that may have originated from the nearby Summit Lake stock. Both Tribe and McGuigan (personal communication) suggested that the deposits could represent original 'epithermal' veins that have been recrystallized and possibly locally remobilized during intrusion of the granodiorite stock.

**BIG MISSOURI MINE AREA**: The geology and mineral deposits of the Big Missouri area are described in detail by Galley (1981) and summarized by Soregaroli and Meade (1983); Holbeck (1983) has completed an ore petrography and trace metal study. The many small, precious metal-rich showings have extensive alteration haloes and are distributed over a 6-kilometres by 1-kilometre area. The deposits have been interpreted to be moderately westward dipping, stratabound, syngenetic quartz-carbonate lenses. These lenses have angular andesite fragments scattered along the footwall contact. The fine to coarsely crystalline quartz-carbonate rock hosts disseminated to semi-massive pyrite with gold-silver values. Several unmineralized quartz-carbonate zones and three small massive pyrite/base metal pods or lenses (Prosperity West, Creek Zone, and TBI-3) also occur in the area. Both hangingwall and footwall consist of andesitic lapilli tuffs and/or crystal tuffs that are moderately to intensely altered; both are cut by barren and mineralized quartz veinlets.

The syngenetic model requires that the andesitic volcanic host rocks of map unit 1 dip gently to moderately (10 to 40 degrees) westward throughout the Big Missouri area. No stratigraphic orientations have been recorded within the andesitic country rocks (Dykes, personal communication, 1983; Galley, 1981). Outcrop is limited, alteration is intense and widespread, and the andesitic tuffs are generally massive. Alldrick (1983, Fig. 67) presented a cross section which relates the observed bedding in the outcrops of map units 2 and 3 on 49 Ridge to postulated dips around the '49' mineral prospect – if the deposit is stratabound.

The regional structural and stratigraphic picture, developed during two years of fieldwork, indicates that strata in the Big Missouri area must be vertical to steeply eastward dipping (Figs. 59 and 60). Outcrops of andesite near Silver Lake that are several hundred metres along strike from the Dago Hill mineralized zones dip 90 degrees to 80 degrees east, supporting the structural picture developed from regional studies.

While the possibility remains that the quartz-carbonate zones are stratabound lenses localized in minor fold structures, the deposits may be epigenetic and localized in structures that crosscut the stratigraphy.

**SILBAK PREMIER MINE**: The geology and mineral deposits of the extensive Silbak Premier mine workings are best described by Langille (1945); additional descriptions are by Burton (1926), White (1939), Grove (1971 and 1973), and Barr (1980). The deposits are high grade and considered to be epithermal precious metal veins hosted either in dense networks of reticulate quartz veinlets or in silica-flooded zones. These vein networks are spatially associated with the 'Premier porphyry'.

Phenocrysts in this porphyritic microdiorite intrusion are bimodal. It contains finer grained (≤5-millimetre) white plagioclase phenocrysts and larger (≤30-millimetre) euhedral, zoned feldspar phenocrysts that appear to be potassium feldspar. In the mine workings there are several apophyses of this intrusive rock into the massive, dark green, andesitic, coarse ash tuff country rock (Langille, 1945, Fig. 2; Barr, 1980, Fig. 10). The total number, overall shape, and distribution of these intrusive bodies is not well established, nevertheless, they represent important exploration guides. The majority of the ore zones are locallized along and 'wrapped around' intrusive/country rock contacts. Other factors must be involved because most of the intrusive contact exposed in the mine workings is unmineralized and in these areas hornfelsing extends only 2 to 3 centimetres into the country rock. In certain areas the 'Premier porhyry' occurs without any phenocrysts (phenocryst density ranges from 0 per cent to 50 per cent). In these areas the intrusive and country rock are almost identical and can only be tentatively separated; the intrusive rock is slightly more blocky and less foliated.

There is no documented evidence available to establish orientation of the andesitic volcanic strata in the mine area. It is generally assumed to be parallel or subparallel to the pervasive foliation in the area which strikes north and dips at 35 to 45 degrees west.

## EXPLORATION

Exploration activity in the Stewart area has been intensive during the past few years. Mining and exploration companies are investigating new mineral discoveries such as: the Consolidated Silver Butte prospect (Esso Minerals Canada), the Angelo vein and D vein extensions (Pacific Cassiar Limited), and the O zone (Scottie Gold Mines Ltd.). In addition, many previously known mines and prospects are being re-evaluated: Big Missouri mine area and Silbak Premier mine area (Westmin Resources Limited), the Scottie prospect (Scottie Gold Mines Ltd.), Indian mine (Esso Minerals Canada), the East Gold mine, the Bayview mine (Kingdom Resources Ltd.), the Prosperity/Porter Idaho mine (Pacific Cassiar Limited), and others. There is also renewed exploration activity in Alaska focussed on similar mineral showings in the same stratigraphic setting, such as: the Mineral Hill area (Greenwich Resources Inc.), the Stoner prospect (Exxon Minerals Company), and Moh's showings (Pulsar Exploration Ltd.).

The Surveys and Mapping Branch (Maps B.C.) of the British Columbia Ministry of Environment has announced release of a new, high-resolution, black and white series of air photographs that cover the Stewart area. The airphoto survey was flown July 27 and 28, 1982; it provides documentation of current glacial extent with a minimum of snow cover. The standard 1:50 000 photographs can be enlarged at least four times (to 1:6250) without significant loss of resolution.

**PROSPECTING:** Intensive prospecting has continued to be the most successful reconnaissance exploration tool throughout the area. Locally, steep topography and cover require different approaches. Base of hill stream sediment and talus sampling led to Northair's discovery of gold-bearing quartz-arsenopyrite-pyrite-epidote veins on the upper slopes of Tide Mountain above the East Gold mine. Boulder tracing at the toes of glaciers and around the margins of snowfields contributed to discoveries by Scottie Gold Mines Ltd. and Skyline Explorations Ltd.

Wide variations in ore mineralogy, textures, gossans, and peripheral alteration among the various mineral deposits preclude establishing a 'short list' of key prospecting guides.

**GEOPHYSICS:** Both Westmin Resources and Esso Minerals have conducted extensive tests of a variety of geophysical systems over their known mineralized zones. The systems tested included horizontal and vertical-loop electromagnetic, VLF electromagnetic, induced polarization, self-potential, and magnetometer surveys. Both companies have independently concluded that time-domain induced polarization (IP) was most effective for following the disseminated to semi-massive mineralization they were dealing with. Induced polarization surveys have allowed both companies to trace mineralized zones through overburden-covered areas and to relocate mineral zones displaced by major and minor fault offsets.

Scottie Gold Mines searched for massive pyrrhotite veins within major fault zones with a magnetometer and a VLF electromagnetic unit.

## CONCLUSIONS

The general stratigraphic section in the Salmon River valley consists of a thick section of andesitic tuffs overlain by interbedded dacitic tuffs and epiclastic beds. This sequence is overlain by a felsic volcanic unit with a locally developed near-vent ash flow facies. The felsic unit is overlain by a thick sedimentary sequence that consists of black, carbonaceous siltstones and overlying sandstones. This regional stratigraphy is folded into a north-northwest/south-southeast-trending doubly plunging syncline which produced a minor regional thrust fault along the base of the black siltstones.

Pyritic ash flow facies (map unit 3g) and overlying transition zone sedimentary rocks of map unit 4 are potential exploration targets for syngenetic volcanogenic massive sulphide deposits. These rocks represent the classic stratigraphic and paleotopographic (?) massive sulphide environment. Visible sulphides, the onset of submarine conditions, and reducing conditions argue that massive sulphide deposits might have formed and been preserved. This favourable zone is exposed for a strike length of 7 kilometres; it could be evaluated rapidly by a rock sampling program along the exposures or by a helicopter-borne electromagnetic survey.

MacIntyre's brief comment (1976, p. 17) about similar stratabound sulphide lenses at a similar stratigraphic horizon in the Tahtsa Lake area 300 kilometres to the southeast suggests that a regional exploration program within and immediately above this distinctive felsic volcanic strata is worth considering.

## ACKNOWLEDGMENTS

Logistical support during the field season was generously provided by Canada Wide Mines Ltd. I am indebted to Scott Angus, Paul Banks, Shaun Dykes, Stu Fraser, Ken Hicks, Paul McGuigan, Norm Tribe, and Paul Wojdak for sharing their knowledge and insights about the geology and mineral deposits of the region. Ian Webster provided capable and cheerful assistance throughout a wet but productive field season.

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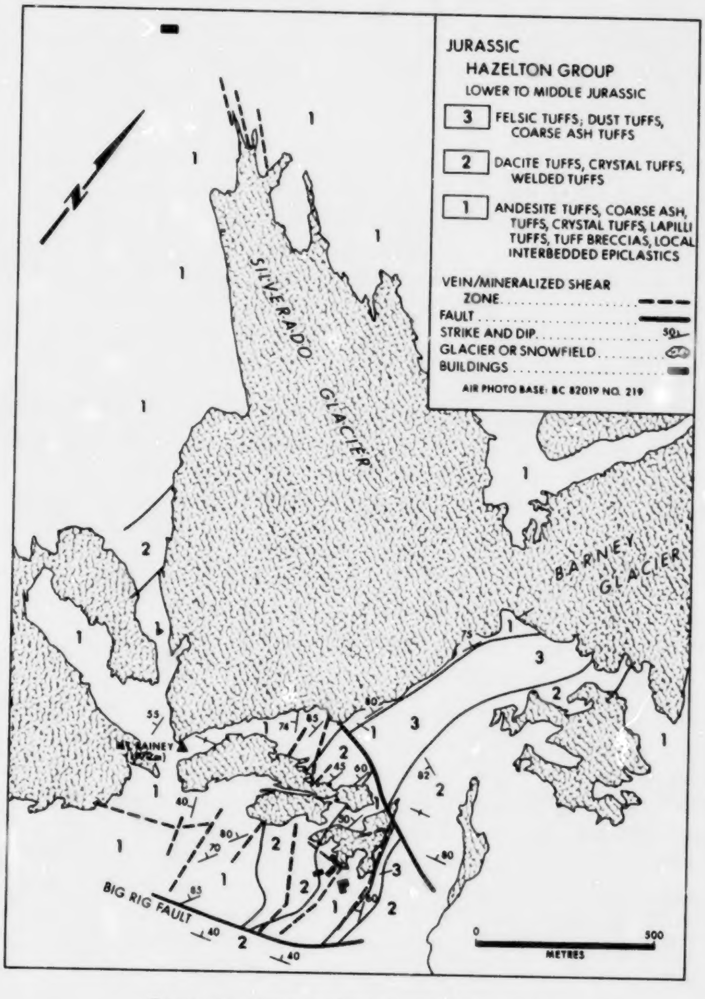
# THE PROSPERITY/PORTER IDAHO SILVER DEPOSITS
# (103P/13)

By D. J. Alldrick and J. M. Kenyon

## INTRODUCTION

The high-grade silver (-lead-zinc) vein deposits of the Prosperity (Mineral Inventory 103P–89) and Porter Idaho (Mineral Inventory 103P–89) mines outcrop on the upper slopes of Mount Rainey, 4.5 kilometres southeast of Stewart. The mine workings are on the south face of the mountain at an elevation of 1 550 metres, overlooking the Kate Ryan Glacier and Ryan Creek (Fig. 62). Access is by helicopter from the Stewart airport 4 kilometres to the northwest, although a hiking trail from the north end of Stewart up Barney Gulch and over or around the Barney Glacier is in fair condition.



N
JURASSIC
HAZELTON GROUP
LOWER TO MIDDLE JURASSIC
3 FELSIC TUFFS; DUST TUFFS, COARSE ASH TUFFS
2 DACITE TUFFS, CRYSTAL TUFFS, WELDED TUFFS
1 ANDESITE TUFFS, COARSE ASH, TUFFS, CRYSTAL TUFFS, LAPILLI TUFFS, TUFF BRECCIAS, LOCAL INTERBEDDED EPICLASTICS
VEIN/MINERALIZED SHEAR ZONE
FAULT
STRIKE AND DIP 50
GLACIER OR SNOWFIELD
BUILDINGS
AIR PHOTO BASE: BC 82019 NO. 219
SILVERADO GLACIER
BARNEY GLACIER
MT. RAINEY
BIG RIG FAULT
0
300
METRES

Figure 62. Geology of the Mount Rainey area.

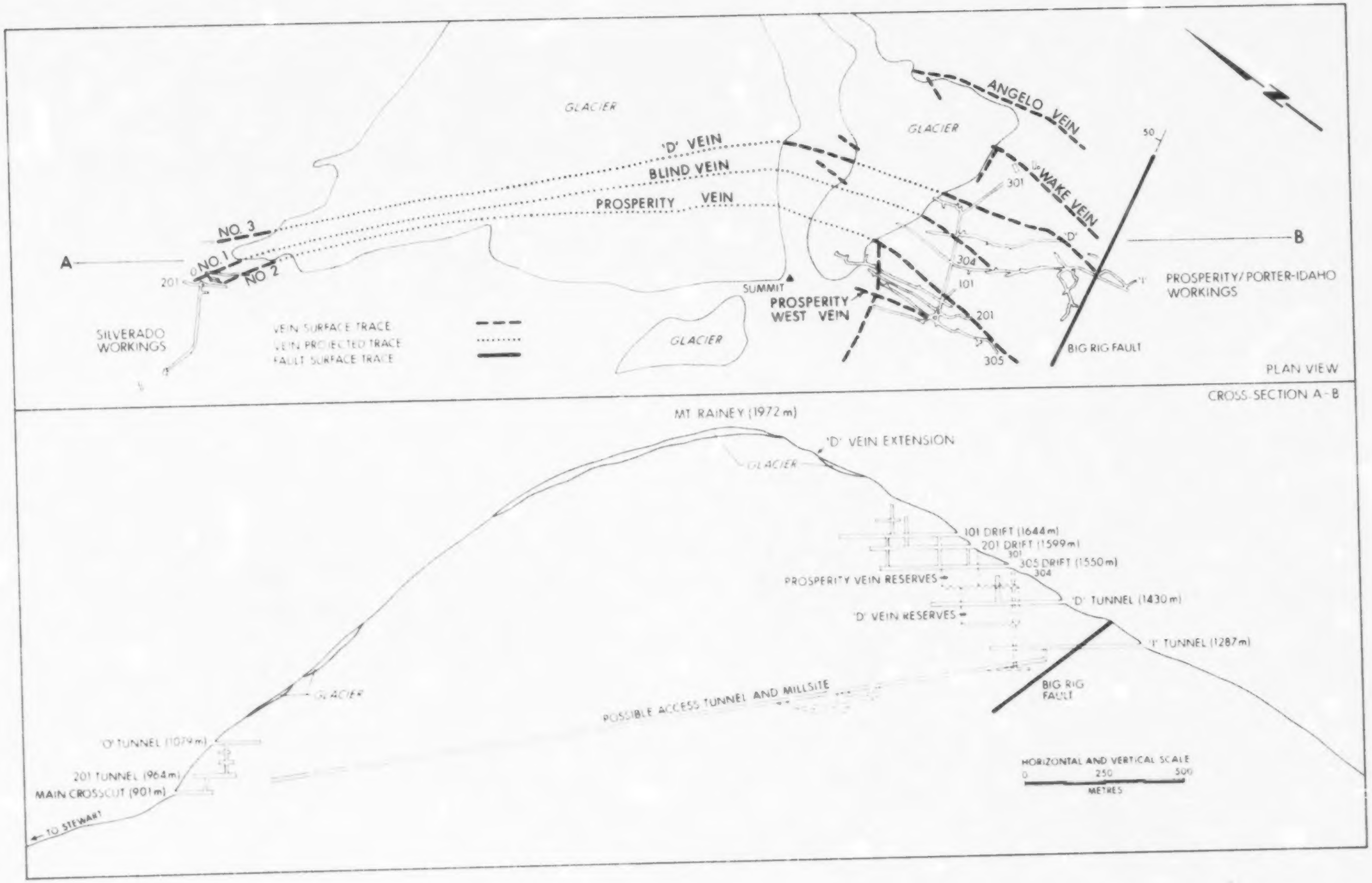


Figure 63. Idealized cross-section through Mount Rainey.

The property is wholly owned by Pacific Cassiar Limited which has been conducting evaluation of ore reserves, rehabilitation of the mine workings, and surface exploration since 1980. This renewed exploration was prompted by elevated silver prices, by the existence of remaining reserves, and by potential for additional ore.

## HISTORY AND PREVIOUS WORK

History and production of the Prosperity/Porter Idaho mine and the nearby Silverado mine (Mineral Inventory 103P–88) were reviewed by Grove (1971). The silver deposits on Mount Rainey have been explored many times since the initial staking of mineralization in 1904 on the Silverado ground. The Porter Idaho ground was staked in 1921, followed by the Prosperity claims in 1926. Premier Gold Mining Company Limited acquired the combined properties in 1928. When the production decision was made silver was $0.56 per ounce. When production ended after 17 months in April 1931 the silver price was $0.28 per ounce.

White (1946) published a detailed description of the Silverado property; however, there is no corresponding detailed description of the Prosperity and Porter Idaho mines. Grove (1971) provides a review of both areas with plans and sections of the mine workings. A company newsletter (1983) presents a north-south cross-section through Mount Rainey that correlates the workings on both sides of the mountain, reproduced here as Figure 63.

## GEOLOGY

Silver deposits of Mount Rainey are contained in a complex andesitic to felsic volcanic sequence that is an extension of lithologies that host precious metal deposits in the Salmon River valley to the north (Alldrick, this volume). Lithologies and stratigraphy are similar in both areas but the structural setting for the Mount Rainey area has not been resolved. Mount Rainey does not contain the thick sections of epiclastic sedimentary rocks or the distinctive felsic volcanic sequence exposed near Mount Shorty Stevenson, 21 kilometres to the north. A simplified stratigraphic column is illustrated on Figure 62.

The host rocks to the mineralization in the Prosperity/Porter Idaho area are predominantly dacitic volcanic rocks varying from crystal tuffs to welded tuffs with minor units of andesitic lapilli tuff and dacitic waterlain tuff. In contrast, the host rocks at the Silverado workings are predominately andesitic coarse tuff breccias (White, 1946). Various dykes that outcrop in and around the Silverado deposits are rare in the Prosperity/Porter Idaho workings.

The Hyder granodiorite, a hornblende granodiorite to quartz monzonite, intrudes the volcanic rocks on the west side of Mount Rainey. The intrusive rock is medium to coarse-grained; the core is unaltered but the outermost 100 to 150 metres is cut by a network of widely spaced (50 to 100 centimetres apart) epidote veinlets.

Volcanic rocks at the intrusive contact show no obvious alteration halo, although the rocks are sheared and cut by epidote and chlorite veinlets. The intruded volcanic section comprises a thick sequence of green andesitic coarse ash tuffs. It contains a one-hundred-metre thick section of massive purple epiclastic conglomerate which outcrops as a prominent knob on the ridge top 700 metres east of the intrusive contact. The volcanic sequence further eastward is a complex of andesitic lithic tuffs, including lapilli and medium to coarse tuff breccias and crystal tuffs, interbedded dacitic crystal tuffs, lapilli tuffs, welded tuffs, and local thin waterlain tuff units and epiclastic conglomerate beds. A thick section of massive felsic tuffs are exposed at the head of Barney Glacier in the northeast part of the area mapped. Volcanic strata further east on Mount Magee, near the contact with sedimentary units, have not been examined. The overall strike of the volcanic units is north-south with dips moderately to steeply westward, but large local variations in the strike have been noted.

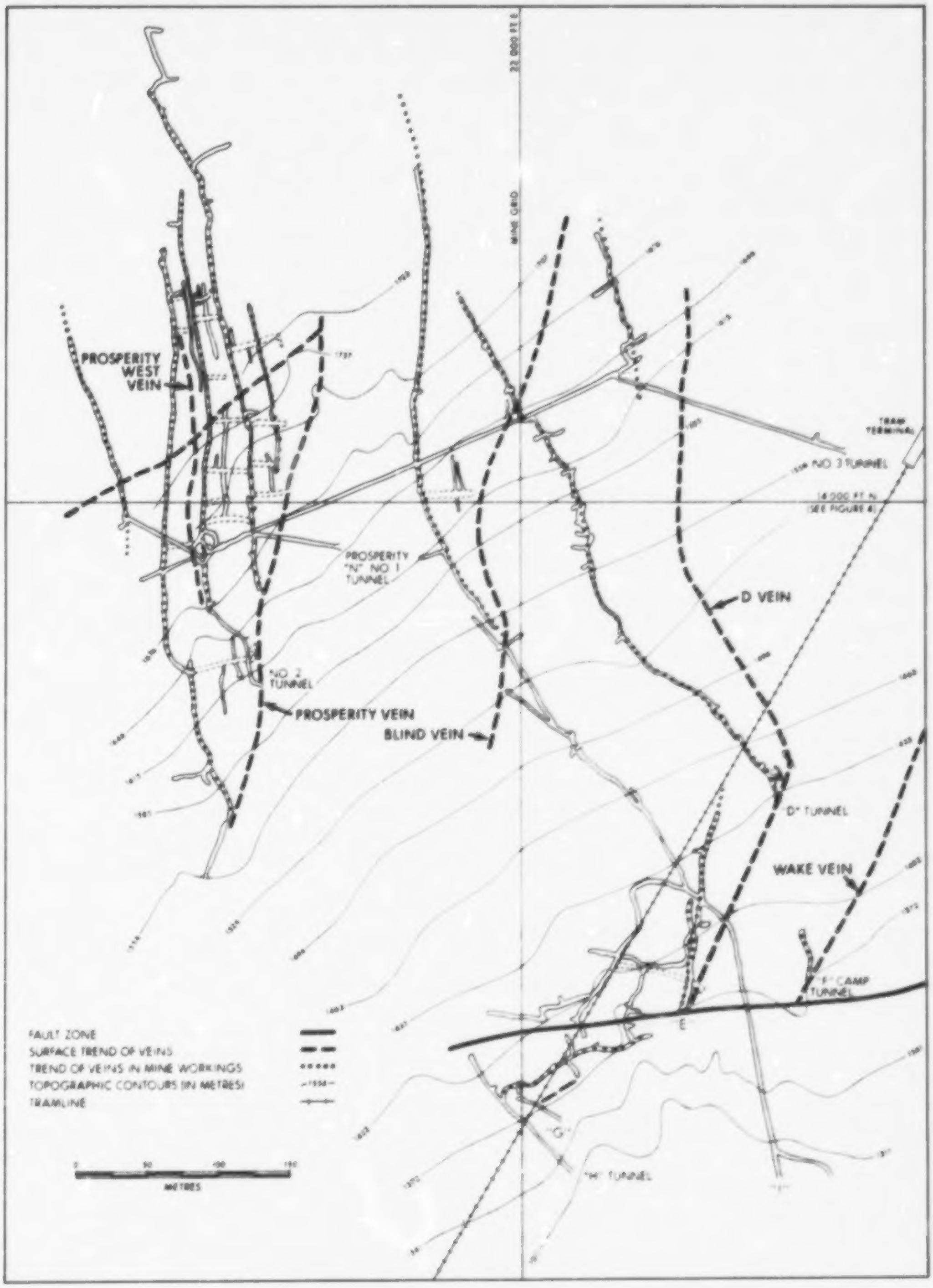


Figure 64. Geology of the Prosperity/Porter Idaho mines property.

## MINERALIZATION AND ALTERATION

The silver mineralization on Mount Rainey occurs in a set of major sub-parallel shear zones (Figs. 62, 63, 64, and 65). Six of these shear structures, spaced roughly 175 metres apart, have been located at the Prosperity/Porter Idaho workings, while four shear structures are known at the Silverado workings, 2.5 kilometres to the north. A few cross-cutting mineralized shear zones have been located both on surface and underground (Figs. 62 and 65) but the economic potential of these cross-cutting shear structures has not yet been evaluated.

Grove (1971) described a minor cross-cutting quartz-breccia vein mineralized with tetrahedrite on the northwest side of Mount Rainey. This deposit was worked in the early 1900's before the discovery of the main Silverado showings nearby in 1927.

At Silverado, White (1946) showed that the mineralized shears trend 155 degrees and dip 65 degrees westward. The structures split along horse-tail-like splays. Some of the shear zones may be spatially associated with felsic dykes which cut the andesite tuff breccias.

At the Prosperity/Porter Idaho workings the major shear zones commonly trend 165 degrees and dip 60 degrees westward. These zones do not splay and are cut but not offset by several lamprophyre dykes in the underground workings. All the shear zones continue northward until covered uphill by talus or ice. Southward, the shears terminate at, or are displaced by, a major north-dipping east-west fault zone called the Big Rig fault.

Detailed mapping in the underground workings by Greig and Kenyon (1982) shows displacement by minor fault structures cross-cutting some of the mineralized shear zones. The shear zones are continuous structures up to 13 metres wide hosting discontinous, mineralized lenses or shoots. In unmineralized or weakly mineralized areas the material within the shear structures consists of varying amounts and sizes of intensely sheared wallrock fragments and blocks set in a gouge or clay matrix. Some sections of the shear zone display late silicification that escaped subsequent shearing. Mineralized zones pinch and swell within the shear zone resulting in well-mineralized shoots that are up to 13 metres wide and 250 metres long. They extend from surface to a depth of 200 metres where old mine workings end, still in mineralization.

Within the strongly mineralized sections of the shear structures the distribution of sulphide mineralization is complex. Early workers reported a mineral suite of galena, sphalerite, native silver, ruby silver, freibergite, and minor amounts of pyrite, chalcopyrite, and argentite. A petrographic description of a grab sample of massive, vein sulphides by J. McLeod of Cominco Ltd. adds polybasite, arsenopyrite, and trace electrum to the mineral suite. The ore zones consist of one or typically two veins of massive sulphide, each about 60 centimetres wide, hosted in sheared, altered, and mineralized country rock. The massive sulphide veins typically follow, or are near, the footwall and hangingwall. They may locally converge and swell to form a single vein up to 2 metres wide anywhere within the zone. These larger veins are composed of argentiferous galena with minor brown to black sphalerite and quartz; they provided 27 268 tonnes of direct shipping ore with an average grade of 2 692 grams per tonne silver, 1.0 gram per tonne gold, 5.1 per cent lead, and 0.1 per cent copper. The smelter contract at that time stipulated a penalty charge for zinc content, consequently sphalerite-rich ore zones were dumped. Samples of massive black coarse-grained sphalerite containing wire silver have been collected from one of the waste dumps.

The shear zone adjacent to these massive sulphide veins is mineralized with disseminations, blebs, and veinlets of quartz, buff-weathering carbonate, abundant black manganese oxide, and sulphide minerals. These mineralized margins to the massive sulphide veins constituted 'waste' during the mining operations of 1930 to 1931 but they are now known to contain up to 690 grams per tonne silver over widths of 5 to 6 metres on both sides of the massive vein.

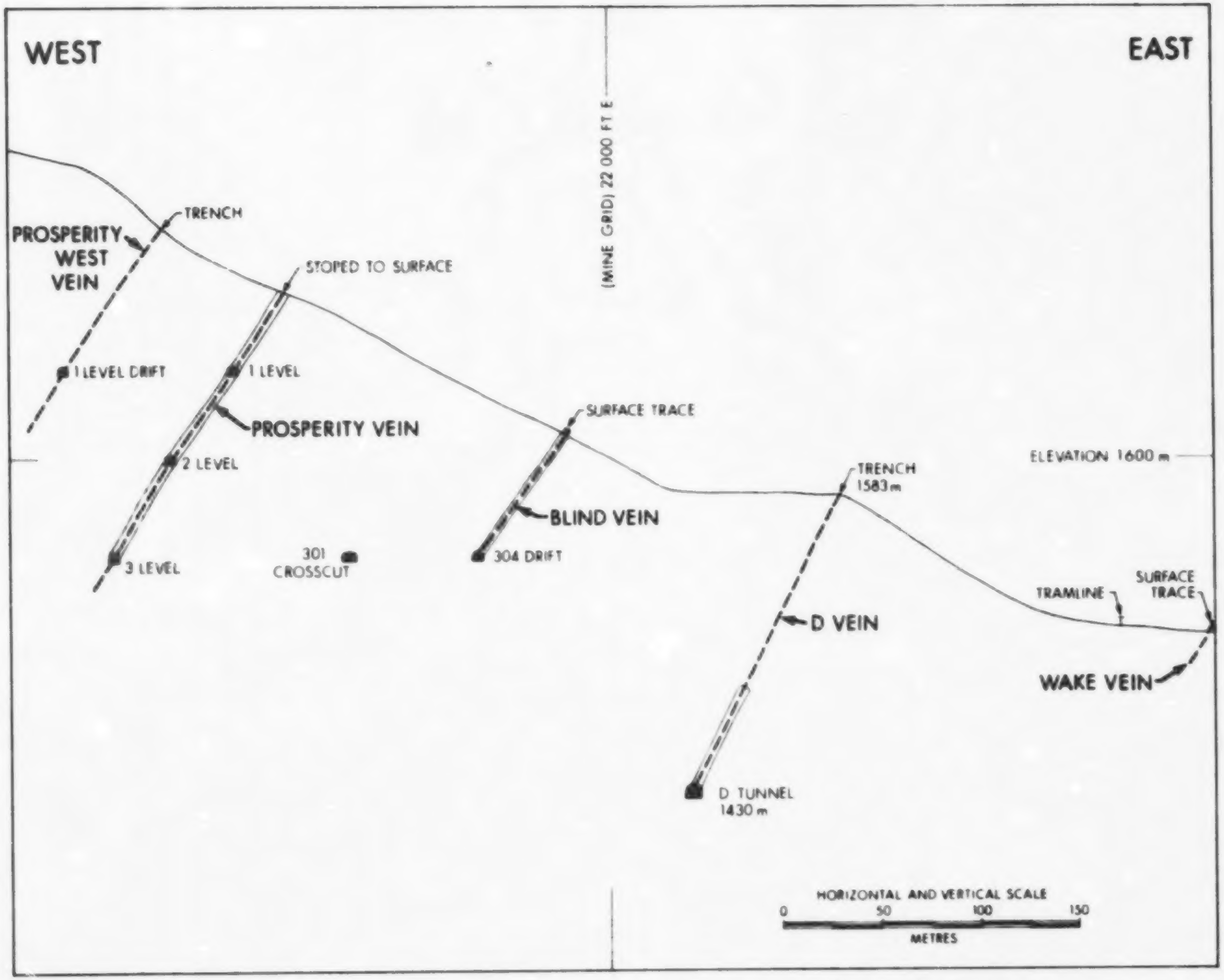


Figure 65. Geologic cross-section through Prosperity/Porter Idaho mines workings, section 14000N.

The shear zones have sharp borders against the country rock and only minor silicification of the volcanic host rocks can be seen in hand sample. There is essentially no known mineralization in the country rock between the shears but one narrow 'blind' mineralized shear has been located 75 metres west of D vein at the 1 430-metre elevation.

Published probable reserves as of December 1983 were 775 800 tonnes of 634 grams per tonne silver from workings which have been assessed.

## EXPLORATION

The recent underground exploration program at the Prosperity/Porter Idaho examined the known reserves remaining in the workings after shutdown in 1931; it was based on an understanding of the original high-grade mining operations and the need to assess the potential of the unexplored strike lengths of the six major shears. The original operations produced direct-shipping ore at a cut-off grade of roughly 785 grams per tonne silver. Much of the mineralized shear zone that constituted 'waste' at that time now provides a substantial tonnage of lower grade ore at current silver prices. The waste dump at the 1 430-metre portal of D tunnel has been bulk sampled and contains reserves of 11 800 tonnes with 396 grams per tonne silver.

The exploration work from 1980-1983 consisted of an underground program to rehabilitate mine workings and systematic percussion drilling of mineralized wallrocks at 15.24-metre (50-foot) centres along the shear zones. The percussion drilling also discovered massive sulphide veins missed by the Premier operation. The surface exploration program consisted of prospecting, detailed geological mapping, geochemical soil and talus sampling, and bulk sampling of waste dumps. Limited geophysical tests have shown little response over mineralized outcrops, and to date, diamond drilling has been limited to three holes cored in 1975. The most effective technique for surface exploration in this area has been intensive prospecting. The snowfields and glaciers on Mount Rainey have retreated substantially in recent years, exposing extensions of known veins, thus reinforcing the concept that the shear structures are continous through the mountain between the Prosperity/Porter Idaho and the Silverado workings (Fig. 63). Icefield retreat has also exposed other areas on the mountain for prospecting. Discovery of new mineralized outcrops has increased the mineralized strike length to a horizontal distance of 750 metres with a vertical relief of 335 metres.

The shear zones are recessive weathering and exposures are sparse. A typical outcrop exposure of the mineralized shears in the Prosperity/Porter Idaho area is a well-sheared zone containing dull, distinctive black and orange coarsely mottled rock due to manganese and carbonate alteration. In some outcrops manganese alteration predominates, producing a massive to sheared sooty black gossan; in other exposures the alteration is predomiantly buff-orange weathering carbonate. Sulphide minerals are partially preserved in some shear-zone outcrops and are leached from others leaving a limonitic boxwork. Shear zones exposed by recent glacial retreat show less oxidation of sulphides; galena and sphalerite are exposed at surface and minor amounts of a bright yellow powdery mineral, greenockite, or hawleyite (?) have been located by Greig and Kenyon; other secondary zinc minerals can be expected to be present.

## ACKNOWLEDGMENTS

Pacific Cassiar Limited provided accommodation and logistical support for the Ministry's field party in 1982 and 1983. Their generous hospitality contributed measurably to the efficiency and productivity of the field program. Ian Webster provided tenacious and cheerful assistance in the field.

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# GEOLOGY OF THE ALSEK–TATSHENSHINI RIVERS AREA
# (114P)

By D. G. MacIntyre

## INTRODUCTION

Geological studies of the Falconbridge Nickel Mines Limited–Geddes Resources Limited's Windy-Craggy deposit began in 1982 (MacIntyre, 1983). An additional 10 days were spent mapping in the vicinity of the deposit during the 1983 field season. A total of 86 geologic stations were established in the map-area, which covered approximately 300 square kilometres (Fig. 66). The primary purposes of this project were to define the stratigraphic and structural setting of the Windy-Craggy deposit and to assess the mineral resource potential of the surrounding area. This report summarizes the preliminary results of this work.

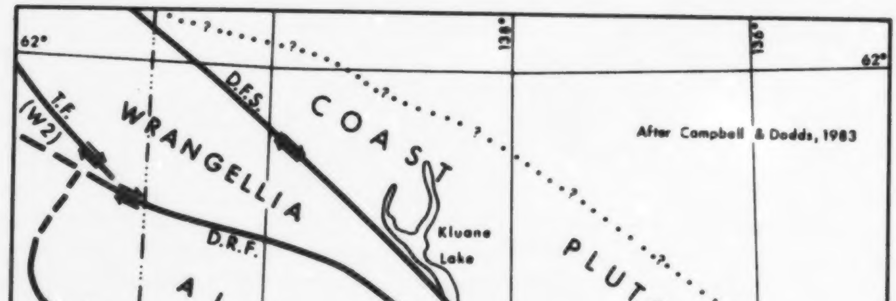

Figure 66. Location of the Alsek-Tatshenshini map-area relative to major tectonic elements as defined by Campbell and Dodds, 1983. B.R.F. = Border Ranges fault; F.F. = Fairweather fault; H.F. = Hubbard fault; D.R.F. = Duke River fault; D.F.S. = Denali fault system; T.F. = Totschunda fault; W1 = Wrangellia.

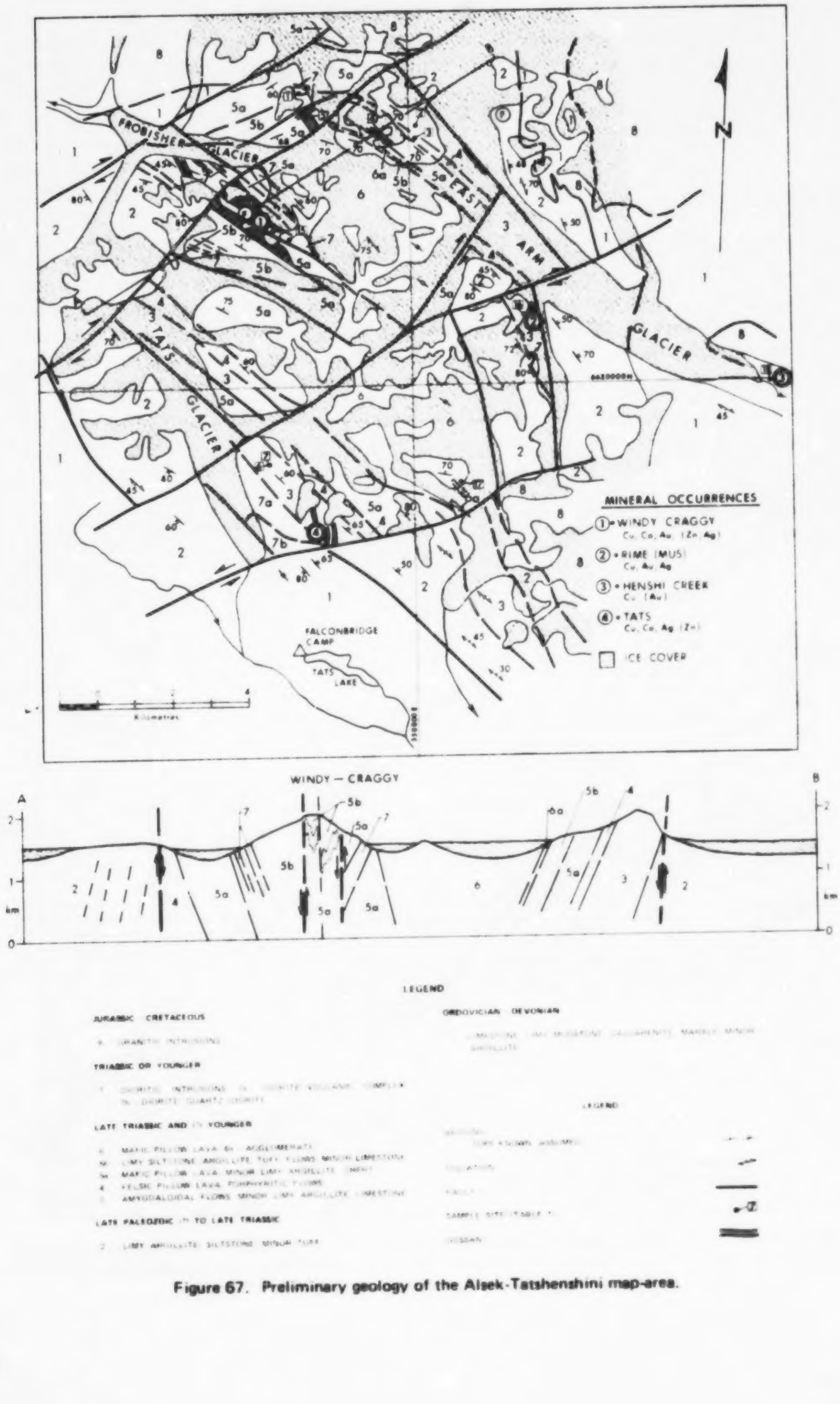
FROBISHER GLACIER
EAST ARM GLACIER
TATS GLACIER
N
MINERAL OCCURRENCES
① = WINDY CRAGGY Cu, Co, Au, (Zn, Ag)
② = RIME (MUS) Cu, Au, Ag
③ = HENSHI CREEK Cu, (Au)
④ = TATS Cu, Co, Ag, (Zn)
ICE COVER
FALCONBRIDGE CAMP
TATS LAKE
Kilometres
0
2
4
WINDY — CRAGGY
A
B
km
LEGEND
JURASSIC CRETACEOUS
8 GRANITIC INTRUSIONS
TRIASSIC OR YOUNGER
7 DIORITIC INTRUSIONS 7a DIORITE-VOLCANIC COMPLEX 7b DIORITE QUARTZ DIORITE
LATE TRIASSIC AND (?) YOUNGER
6 MAFIC PILLOW LAVA 6a AGGLOMERATE
5b LIMY SILTSTONE ARGILLITE TUFF FLOWS MINOR LIMESTONE
5a MAFIC PILLOW LAVA MINOR LIMY ARGILLITE CHERT
4 FELSIC PILLOW LAVA PORPHYRITIC FLOWS
3 AMYGDALOIDAL FLOWS MINOR LIMY ARGILLITE LIMESTONE
LATE PALEOZOIC (?) TO LATE TRIASSIC
2 LIMY ARGILLITE SILTSTONE MINOR TUFF
ORDOVICIAN DEVONIAN
1 LIMESTONE LIMY MUDSTONE CALCARENITE MARBLE MINOR ARGILLITE
LEGEND
BEDDING (TOPS KNOWN, ASSUMED)
FOLIATION
FAULT
SAMPLE SITE (TABLE 1)
GOSSAN

Figure 67. Preliminary geology of the Alsek-Tatshenshini map-area.

The map-area is part of the Alsek Ranges of the St. Elias Mountains; it is characterized by jagged ridges and peaks rising to 2 200 metres above a base elevation of 800 to 1 000 metres. Almost all the cirques and valleys in the area are occupied by glaciers. Outcrop is limited by the extent of ice cover. The steep and unstable nature of much of the outcrop in the area made mapping difficult; many areas could not be sampled for safety reasons. Marginal weather conditions also restricted access to higher elevations during the mapping project. Consequently much of the area has been mapped from a distance or via helicopter with geologic contacts inferred rather than defined. Figure 67 summarizes the geology as it is known to date.

## GEOLOGIC SETTING

The Alsek-Tatshenshini map-area is part of the Alexander and St. Elias terrane of the Insular Tectonic Belt (Fig. 66). Recent geologic mapping by Campbell and Dodds (1983) showed this area to be underlain by complexly deformed Paleozoic clastic and carbonate rocks of relatively low metamorphic grade. Mafic volcanic units, lithologically similar to those exposed in the vicinity of the Windy-Craggy deposit, were known to occur in the Early Paleozoic part of the stratigraphic succession; for this reason the deposit was believed to be Paleozoic in age. However, limy beds in the stratigraphic hangingwall of the deposit have consistently yielded Late Triassic conodonts (MacIntyre, 1983). The age of the footwall rocks is, however, unknown.

## GEOLOGY

The map-area is underlain by intermediate to mafic submarine volcanic units with variable amounts of interbedded limy argillaceous sedimentary rocks. These rocks are believed to be predominantly Late Triassic or younger in age and to overlie an Early to Middle Paleozoic clastic and carbonate sequence (unit 1). The stratigraphic succession described in this report is based mainly on traverses completed north of the East Arm glacier where a relatively complete southwest-dipping section is exposed and accessible. It is assumed that this section is both representative for the area as a whole and that it is not complicated by major faults.

## STRATIGRAPHY

The stratigraphy (Fig. 68) has been divided into map units on a lithological basis. The oldest known part of the section (unit 1) is represented by a thick sequence of laminated carbonate, limy mudstone-siltstone, and massive limestone (upper part). Apparently overlying this unit, but generally in fault contact, is a thick sequence of limy argillaceous rocks (unit 2). These rocks are overlain by andesitic flows with minor intercalations of limy argillite and limestone (unit 3). A thin unit of felsic and mafic pillow lavas and porphyritic flows (unit 4) locally separates these rocks from overlying pillowed and non-pillowed intermediate to mafic flows and tuffs with interbedded limy argillite, siltstone, and minor amounts of chert and limestone (unit 5). Overlying unit 5 is a thick (>1 500 metres ?) pile of mafic pillow lava (unit 6) that has no appreciable amount of interbedded sedimentary rock. Fine to medium-grained dioritic sills and dykes (unit 7) occur throughout the Triassic succession and Jurassic/Cretaceous age plutons (unit 8) occur on the northwest and east edges of the map-area.

**UNIT 1:** Map unit 1 consists of medium to thin-bedded, grey, cream, and orange-brown-weathering limestone or marble with interbedded calcarenite and limy argillaceous siltstone. These rocks are well exposed in the creek valley south of the Tats showing, where highly contorted bands of marble and calcarenite crop out on the north-facing slope. A major fault occupies the valley bottom and separates these calcareous rocks from massive volcanic rocks and diorite north of the creek.

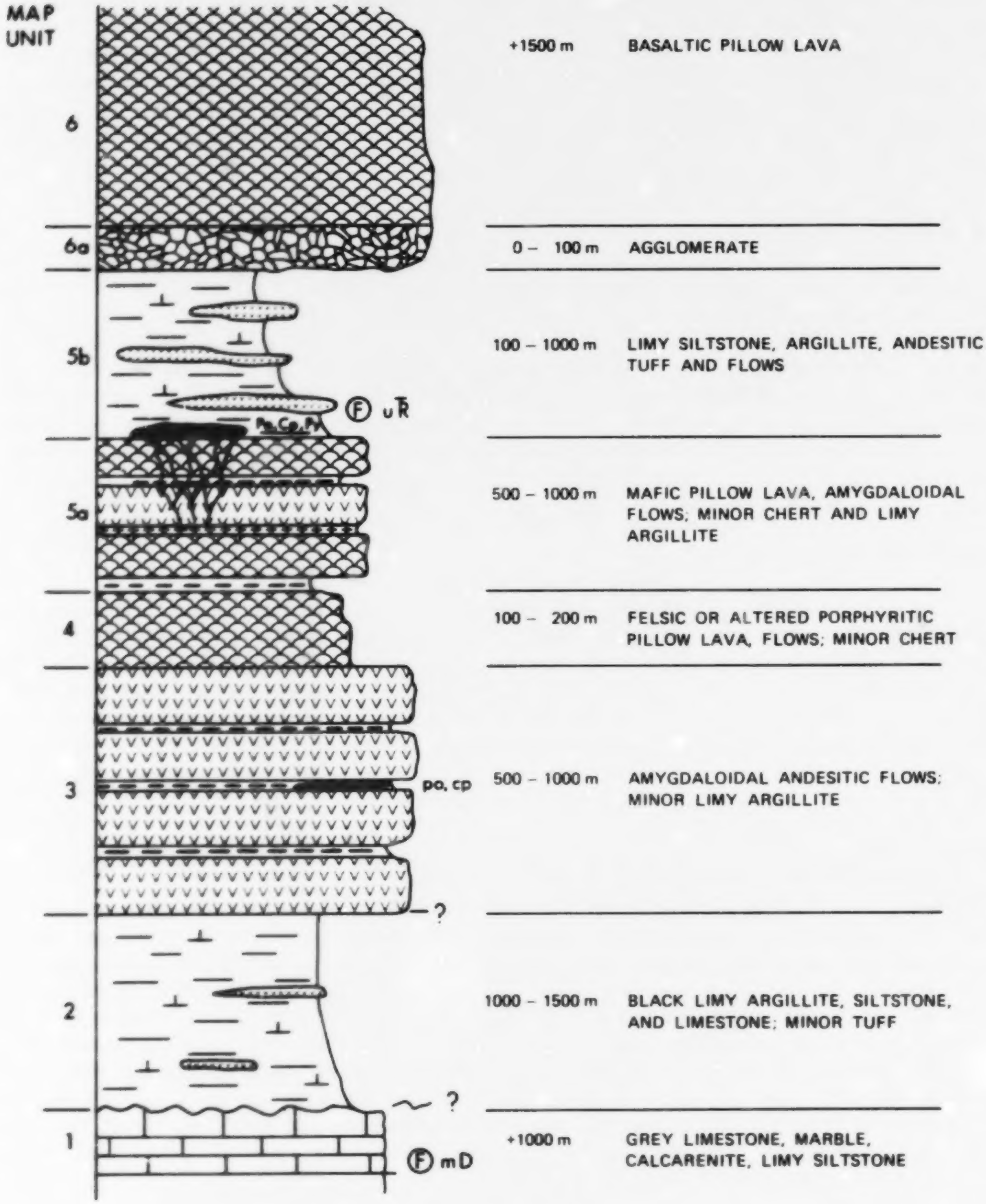
MAP UNIT
6
+1500 m
BASALTIC PILLOW LAVA
6a
0 – 100 m
AGGLOMERATE
5b
100 – 1000 m
LIMY SILTSTONE, ARGILLITE, ANDESITIC TUFF AND FLOWS
Ⓕ uTR
Po,Cp,Py
5a
500 – 1000 m
MAFIC PILLOW LAVA, AMYGDALOIDAL FLOWS; MINOR CHERT AND LIMY ARGILLITE
4
100 – 200 m
FELSIC OR ALTERED PORPHYRITIC PILLOW LAVA, FLOWS; MINOR CHERT
3
po, cp
500 – 1000 m
AMYGDALOIDAL ANDESITIC FLOWS; MINOR LIMY ARGILLITE
?
2
1000 – 1500 m
BLACK LIMY ARGILLITE, SILTSTONE, AND LIMESTONE; MINOR TUFF
?
1
+1000 m
GREY LIMESTONE, MARBLE, CALCARENITE, LIMY SILTSTONE
Ⓕ mD

Figure 68. Preliminary stratigraphic column for the Alsek-Tatshenshini map-area.

Grey-weathering limestone also crops out northeast of the East Arm glacier along the crest of a northwest-trending ridge. Apparently this unit has yielded Devonian macrofossils (Knopf and Valle, 1981) and underlying black limy argillites contain Late Eifelian to Early Givetian conodonts (R. B. Campbell, personal communication). The lower half of the ridge is underlain by black-weathering shales which apparently dip northeastward underneath the limestone unit. It is not certain whether these rocks stratigraphically underlie the Devonian limestone or are part of the Triassic succession (unit 2) that is in fault contact with the limestone.

**UNIT 2:** Black to dark grey-weathering limy argillaceous siltstone and shale are the predominant lithologies in map unit 2. Thin beds of tuff also occur locally within this unit, which for the most part is recessive in nature. This unit is well exposed west of the Tats glacier, northeast of the East Arm glacier, and on the east side of the south-trending glacier that forms the eastern margin of the map-area. Tuff bands within this unit help outline northwest-verging isoclinal folds.

Stratigraphic relationships between unit 2 and units 1 and 3 are not well established. Norian (early Late Triassic) age conodonts have been extracted from samples of lithologically similar rocks exposed on the ridge west and north of the Tats glacier (C. J. Dodds, personal communication), but it is not certain if these limy argillaceous rocks are part of unit 2 or are a volcanic-deficient facies equivalent of unit 5b. Hopefully samples collected from unit 2 elsewhere in the map-area will yield diagnostic conodont fauna to help resolve the relative stratigraphic position of these rocks.

**UNIT 3:** Map unit 3 consists mainly of massive, thick-bedded, locally amygdaloidal, grey to orangy brown-weathering, intermediate volcanic flows and tuff beds separated by thin beds of limy siltstone and banded limestone. Microdioritic sills and dykes are also common within this unit. These rocks are well exposed north of the East Arm glacier where they dip steeply to the southwest and outcrop as a prominent northwest-trending ridge. The general lack of pillowed flows distinguishes this unit from compositionally similar units which are believed to be higher up in the Triassic succession. This criteria may not be valid and the unit may be a non-pillowed facies equivalent of unit 5a.

**UNIT 4:** A distinctive unit of felsic pillow lava crops out on the west-facing slope of the ridge east of the Tats glacier. The pillow lava is typically porphyritic with a dark cherty rind outlining pillows. Non-pillowed porphyritic flows and felsic crystal and ash tuff are also included with this unit. Similar rocks crop out at the same stratigraphic position on the south-facing slope of the ridge north of the East Arm glacier. This unit may prove to be an important marker unit within this sequence of predominantly intermediate to mafic volcanic rocks.

The original chemical composition of unit 4 rocks is not certain. Although the porphyritic pillow lavas are relatively siliceous and light coloured these characteristics may be due to superimposed hydrothermal alteration that may be genetically related to massive sulphide deposits that apprently occur higher up in the stratigraphic sequence.

**UNIT 5:** Map unit 5 can be subdivided into a lower unit (5a) which consists of pillow lava and amygdaloidal flows with minor intercalations of limy argillite, siltstone, and chert and an upper unit (5b) which is predominantly limy siltstone and argillite interbedded with andesitic tuffs and flows. The volcanic flows of unit 5a appear to be somewhat more basaltic and pervasively altered to a chlorite-carbonate assemblage than the predominantly unaltered to weakly altered tuffaceous rocks of unit 5b. Zones of disseminated and stringer pyrite both crosscut and parallel bedding within unit 5a. Rocks of this unit are believed to form the stratigraphic footwall of the Windy-Craggy deposit.

The thickness and percentage of intercalated volcanic rocks are quite variable in unit 5b. Immediately southwest of Windy-Craggy this unit appears to be over 1 000 metres thick and is predominantly limy

Plate VIII. View southwest toward Windy-Craggy. Arrows point to drill locations on ridge. Rocks in foreground are amygdaloidal flows of unit 3. Peak on the left is capped by a southwest-dipping dioritic sill that intrudes pillow lava of unit 6.

siltstone; north of the East Arm glacier volcanic rocks predominate and the unit is probably less than 200 metres thick. Assuming there are no major faults that cut out or repeat parts of these sections (a dangerous assumption!), a local thickening of this unit in the vicinity of the Windy-Craggy deposit is inferred. Perhaps a structurally controlled sedimentary trough was present in Late Triassic time, with limy detritus and rift-related flows and tuffs accumulating within the trough.

**UNIT 6**: Map unit 6 is almost entirely massive mafic pillow lava; there is little or no intercalated sedimentary rock. This unit is very resistant and forms jagged ridges and near-vertical cliff faces in the area east and southeast of the Windy-Craggy deposit. Here the unit appears to exceed 1 500 metres in thickness; its top has not yet been recognized. Agglomerate consisting of drawn out clasts of lava suspended in a muddy or tuffaceous matrix (unit 6a) occurs at the base of the pillow lava sequence. These rocks are very distinctive and may prove to be a useful marker horizon for the map-area.

The great thickness of mafic pillow lava represented by unit 6 implies that a prolonged period of submarine extrusive activity followed formation of the Windy-Craggy deposit and deposition of turbiditic sediments of unit 5b. The pillow lavas apparently occupy the core of a northwest-trending synclinorium which also coincides with the greatest thickness of unit 5b as mentioned previously. These observations are compatible with a depositional model in which sediments and submarine volcanic rocks accumulated within a trough centred on a submarine rift system located within a back arc sedimentary basin.

**UNIT 7**: Numerous dykes and sills of grey-weathering medium to fine-grained dioritic rock occur within map units 2 through 5, particularly in the vicinity of the Windy-Craggy deposit. These intrusive rocks are texturally and probably compositionally identical to flows within units 3 and 5b and they are assumed to be the subvolcanic equivalents of these rocks. The sills are difficult to recognize unless contacts are well-exposed and they may be more abundant than presently recognized. Isotopic age dating and petrographic and geochemical studies will be undertaken to help define the volcanic-plutonic relationships.

A diorite-volcanic complex (unit 7a) is exposed along the bottom half of the ridge east of the Tats glacier. This complex is characterized by very coarse-grained hornblende-rich diorite and partly to totally recrystallized mafic volcanic flows. The diorite in places appears to have formed as a result of recrystallization of the mafic volcanic rocks. Segregations of mafic-rich diorite are also present and locally crosscut the volcanic stratigraphy. Hornblende-rich dykes cut rocks in the vicinity of the complex; they may be genetically related to the core of the complex. In one locality a breccia dyke was observed with clasts of volcanic rock that are partially to totally replaced by hornblende and suspended in a finer grained hornblende diorite matrix.

Medium to coarse-grained diorite to quartz diorite (unit 7b) crops out in the lower part of the creek draining the Tats showing and in the major creek valley southwest of the showing. This intrusive body appears to form the core of the diorite-volcanic complex; perhaps the complex represents a transitional zone between the intrusive and overlying volcanic strata.

**UNIT 8**: Map unit 8 includes granitic rocks of probable Jurassic/Cretaceous age. These rocks are part of a series of intrusive bodies that crop out in the Alsek-Tatshenshini area. Potassium-argon isotopic ages of 156±19, 136±5, and 141±8 Ma were determined by the Geological Survey of Canada on hornblende and biotite-hornblende pairs extracted from intrusive bodies east and southwest of the map-area (C. J. Dodds, personal communication).

## STRUCTURE

Major northeast and northwest-trending faults that offset steeply tilted fault blocks dominate the structure of the map-area. Isoclinal folds with northeast-dipping axial planes and northwest plunges occur within

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Au | <0.3 | <0.3 | <0.3 | <0.3 | <0.3 | <0.3 | <0.3 | <0.3 | 0.3 | <0.3 | <0.3 | <0.3 | 0.3 | 0.3 | <0.3 | 84 | <0.3 | 0.7 | 54 |
| Ag | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | 22 | <10 | <10 | <10 | 29 | <10 | <10 | 42 | <10 | <10 | 18 |
| Cu | 49 | 76 | 89 | 108 | 110 | 370 | 320 | 140 | 19.0% | 400 | 600 | 0.37% | 13.5 % | 1.19% | 230 | 0.86% | 160 | 0.38% | 0.25% |
| Pb | 9 | 21 | 19 | 43 | 7 | 10 | 6 | 11 | 9 | 3 | 8 | 15 | 8 | 7 | 18 | 104 | 25 | 370 | 77 |
| Zn | 175 | 350 | 370 | 178 | 64 | 74 | 111 | 51 | 226 | 59 | 93 | 40 | 0.18% | 204 | 73 | 318 | 208 | 310 | 82 |
| Co | 20 | 4 | 45 | 19 | 21 | 94 | 51 | 62 | 88 | 42 | 17 | 0.14% | 0.12% | 580 | 34 | 5 | 42 | 6 | 750 |
| Ni | 33 | 31 | 400 | 67 | 93 | 52 | 34 | 42 | <2 | 18 | 20 | 3 | 57 | 105 | 103 | 6 | 143 | 6 | 7 |
| Mo | 3 | <3 | 30 | 6 | 11 | 8 | 3 | <3 | 5 | 6 | 5 | 57 | 57 | <3 | 36 | 26 | 14 | 5 | 26 |
| Sb | <3 | <3 | <3 | <3 | <3 | <3 | <3 | <3 | 3 | <3 | <3 | <3 | <3 | <3 | <3 | 16 | <3 | <25 | <25 |
| Ba | 130 | <20 | 855 | 2663 | 108 | 21 | <20 | 97 | <20 | <20 | 1548 | <20 | <20 | <20 | 411 | <20 | 86 | — | — |
| Hg (ppb) | <15 | 32 | 232 | 35 | 19 | 26 | 28 | <15 | 17 | 19 | 28 | 31 | 71 | 25 | 15 | 235 | <15 | 216 | 102 |

NOTE: Values in ppm unless otherwise indicated.

**SAMPLE DESCRIPTIONS**

1 – Altered pillow lava with disseminated pyrite, unit 5a.
2 – Limestone with pyrite laminae, unit 3.
3 – Pyritic shear zone within brecciated flows, unit 5a.
4 – Pyritic zone within massive flows, unit 5a (distal exhalite ?)
5 – Pyritic zone in massive pillow lava, unit 5a.
6 – Sheared pyritic zone in limy argillite, unit 3.
7 – Sheared pyritic zone in limy argillite, unit 3.
8 – Pyritic chloritized volcanic flow, TATS property, unit 3.
9 – Massive chalcopyrite from thin shear zone cutting massive flows, TATS property, unit 3.
10 – Massive pyritic flow, TATS property, unit 3.
11 – Feldspar porphyry dyke upstream from TATS showing, unit 8.
12 – Massive granular pyrrhotite, minor chalcopyrite, magnetite, TATS showing above creek bed, unit 3.
13 – Massive chalcopyrite and pyrrhotite in creek bed, TATS showing.
14 – Pyritic shear zone down stream from TATS showing.
15 – Pyritic zone cutting altered pillow lava, east of Windy-Craggy, unit 5a.
16 – Banded calcite, pyrrhotite, pyrite, and minor chalcopyrite in limy argillite, RIME property (X-showing of former MUS claims).
17 – Pyritic zone in pillow lava, unit 6.
18 – Massive pyrrhotite, chalcopyrite boulder, HENSHI Creek.
19 – Banded calcite, pyrrhotite, pyrite, and minor chalcopyrite in limy argillite, RIME property (X-showing of former MUS claims).

incompetent limy argillaceous beds and in the massive sulphide zone at the Windy-Craggy property. Elsewhere massive volcanic units do not appear to be significantly deformed, although interbeds of limy argillaceous rocks are often sheared and tightly folded, suggesting movement was concentrated along these less competent beds. A broad syncline is defined by stratigraphic tops as deduced from pillow orientations and the areal distribution of unit 6 (Fig. 67), which is assumed to occur high in the Triassic stratigraphic succession.

## MINERAL OCCURRENCES

**WINDY–CRAGGY (Mineral Inventory 114P-2):** Exploration work continued on the Falconbridge Nickel Mines Limited–Geddes Resurces Limited's Windy-Craggy deposit during the 1983 field season. A total of 4 141 metres of drilling was completed in nine drill holes. This work confirmed the northwest extension of the massive sulphide deposit. Drill hole 83-14, which tested the ground between drill holes 82-11 and 82-12 (MacIntyre, 1983) intersected 61.23 metres averaging 1.21 per cent copper, 11 grams per tonne (0.32 ounce per ton) gold, and 11.6 grams per tonne (0.34 ounce per ton) silver (George Cross Newsletter, No. 197, October 12, 1983). This intersection included a 23.7-metre section averaging 19.9 grams per tonne (0.58 ounce per ton) gold. These results indicate that the Windy-Craggy deposit may also have very significant concentrations of gold. Final results of the 1983 drilling program have not yet been made public.

One of the primary objectives of this project was to define the stratigraphic position of the Windy-Craggy deposit. On the basis of mapping completed to date it appears that the mineralized zone occurs at the transition between units 5a and 5b. That is, the stratigraphic footwall consists of pillow lava with minor intercalations of chert and limy argillite; the stratigraphic hangingwall consists of limy siltstone and argillite with interbedded andesitic tuff and flows. These stratigraphic units are offset by high-angle reverse and normal faults (*see* cross section, Fig. 67).

A similar stratigraphic succession to that hosting the Windy-Craggy deposit is exposed on the north side of the East Arm glacier. Zones of pervasive chlorite and sericite alteration with disseminated and stringer pyrite mineralization do occur in this part of the volcanic sequence, typically producing prominent gossans. So far no stratabound massive sulphide mineralization has been discovered. Analyses of samples from these zones (samples 4 and 5, accompanying table) indicate relatively low base and precious metal contents. There may be an enrichment of barium in sample 4.

**TATS:** In addition to Windy-Craggy there are two other massive sulphide occurrences in the map-area, namely the Tats and Rime (Mus). The Tats showing, which is also held by Falconbridge Nickel Mines Limited, is located in a south-flowing creek gully just below a small cirque glacier in the first major valley north of Tats Lake (Fig. 69). The showing occurs within a broad, north-trending pyritic zone within massive amygdaloidal flows. These rocks are tentatively assigned to map unit 3.

A thin (less than 2 metres) band of massive chalcopyrite and pyrrhotite exposed in the creek bed comprises the Tats showing. A sample of massive sulphide from this showing contained 13.5 per cent copper, 0.12 per cent cobalt, 0.18 per cent zinc, and 29 ppm silver (sample 13, accompanying table). Small elongate crystals of black actinolite (X-ray diffraction identification) occur within the massive chalcopyrite along with minor amounts of chlorite, epidote, and quartz.

Outcrops of pyritic volcanic flows immediately above the creek bed showing contain bands of coarse-grained pyrrhotite and magnetite with only minor chalcopyrite. Cobalt is also enriched in this sulphide zone with one sample averaging 0.14 per cent (sample 12, accompanying table). Zinc and silver were low, however, in contrast to the creek bed showing. Upstream, a thin dyke of feldspar porphyry cuts the pyritic zone. This dyke is also mineralized with small flecks of malachite and disseminated pyrite (sample 11, accompanying table).

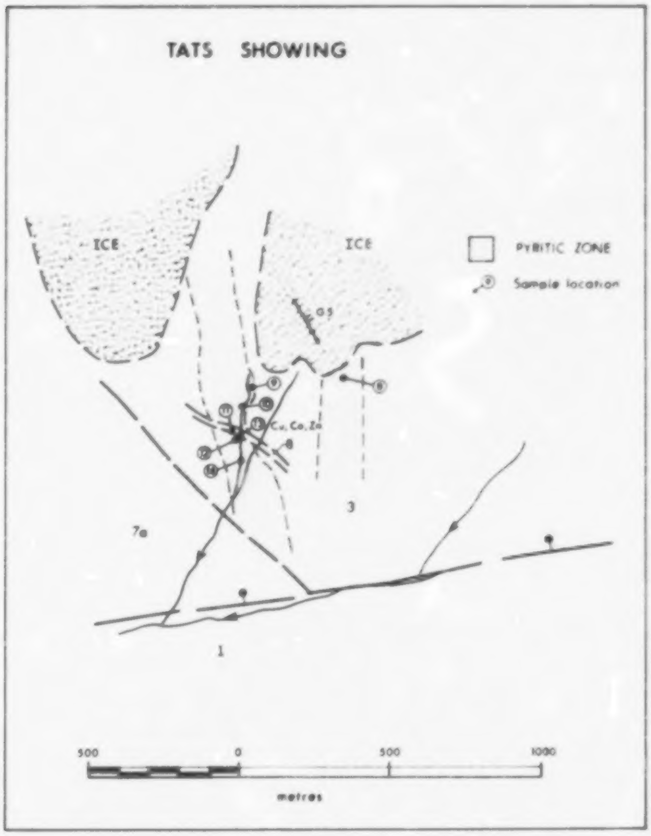

Figure 69. General geology and sample locations, Tats showing. *See* Figure 67 for explanation of map symbols.

**RIME:** The Rime claims straddle the East Arm glacier. The area was formerly held by Swiss Aluminium Company of Canada Ltd. (Mus claims); the main showing was known as the 'X-showing' (Knopf and Valle, 1981). The area has recently been restaked by St. Joe Canada Inc. and airborne geophysical surveys were conducted over the property during the 1983 field season. One of the main targets is a large magnetic anomaly that occurs under the East Arm glacier at the junction of the north and west branches.

The main showing on the Rime claims (X-showing) is a thin zone of banded pyrrhotite, chalcopyrite, and calcite in tightly folded limy argillites. The limy argillite occurs within a sequence of massive amygdaloidal flows that are assigned to map unit 3. Two samples from the showing were analysed for trace and precious metal content (samples 16 and 19, accompanying table) and were found to contain 84 and 54 grams per tonne gold and 42 and 18 grams per tonne silver respectively. Antimony was also slightly enriched whereas cobalt content was very low relative to the anomalous concentrations at the Tats and Windy-Craggy deposits. Additional work is required to evaluate the overall significance of very high gold values in what appears to be stratiform sulphide mineralization.

Thin laminae of pyrrhotite also occur in limy argillite interbeds in exposures of unit 3 north of the East Arm glacier. A sample of massive pyrrhotite from this occurrence (sample 2, accompanying table) contained only a slight enrichment in zinc.

**HENSHI CREEK:** Boulders of massive pyrrhotite with variable amounts of intergrown chalcopyrite have been deposited at the toe of the East Arm glacier (Henshi Creek showing, No. 3, Fig. 67). The source of these boulders is still uncertain. It is most likely that they are derived from bedrock under the glacier rather than from medial and lateral moraines on the ice surface. Chemical analysis of a sample of one of the boulders indicates an anomalous gold concentration (sample 18, accompanying table), but values are much lower than those obtained at the X-showing.

## CONCLUSIONS

Fieldwork in the Alsek-Tatshenshini Rivers area indicates that a thick (>3 000 metres ?) section of Late Triassic andesitic to basaltic flows and limy argillaceous sedimentary rocks is preserved within a roughly rectangular, fault-bounded area. Stratabound massive sulphide deposits occur at several different stratigraphic levels within the Triassic succession; broad zones of disseminated stringer sulphides both crosscut and parallel the stratigraphy. These sulphide zones appear to be spatially associated with fine-grained dioritic sills and dykes in underlying rocks. These intrusive rocks are lithologically and probably compositionally similar to flows within the succession. The presence of a structurally controlled trough is inferred by anomalous thickening of sedimentary and volcanic units in the vicinity of the Windy-Craggy deposit.

The modern day Guaymas Basin in the Gulf of California (for example, Scott, *et al.*, 1983) is favoured as the type of environment in which the mineral deposits of the area formed. That is, hydrothermal vents are inferred to have occurred within a rift trough localized on a spreading centre within a sedimentary basin. The inferred trough was the site of rapid accumulation of submarine flows and clastic and carbonate detritus and injection of subvolcanic dioritic intrusions both before and after the main mineralizing events. No ophiolite sequence has yet been observed in the area, although the diorite-volcanic complex exposed near the Tats showing may have formed in a manner analogous to that proposed for ophiolite complexes. The lack of well-developed ophiolite complexes suggests that the inferred spreading centre was short lived and did not evolve past the earliest stages of crustal spreading.

One of the most significant results of work done in the Alsek-Tatshenshini Rivers area during 1983 is recognition that the deposits of the area may contain significant amounts of gold. Undoubtedly this will have a profound influence on future exploration, not only at Windy-Craggy but also at other prospects in the area.

## ACKNOWLEDGMENTS

The author would like to thank Falconbridge Nickel Mines Limited and Geddes Resources Limited for logistical support during the mapping project. Without their assistance the project would not have been possible. I would also like to acknowledge Dick Campbell, Chris Dodds, and Ken Dawson of the Geological Survey of Canada for reviewing the original manuscript and for sharing the geologic data they acquired during an earlier visit to the area. Some of the geology shown on the geologic map accompanying this report is derived from their observations. Finally I would like to thank Joe Cadham, pilot for Pacific Helicopters, for excellent service under less than ideal conditions and Mike Fournier for his cheerful and very able assistance in the field.

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# BRITISH COLUMBIA
# GEOCHEMICAL RECONNAISSANCE SURVEY DATA SUMMARY

### By W. M. Johnson

During the British Columbia Regional Geochemical Survey (RGS) and its predecessor, the joint Federal/Provincial Uranium Reconnaissance Program (URP), more than 18 000 stream sediment and stream water samples from seventeen 1:250 000 National Topographic System (NTS) map sheets in the province were collected and analysed. Unless the exploration company or individual prospector wishing to use this information has access to a computer this represents an overwhelming amount of data. This report gives a compilation of data grouped according to the dominant rock type in the drainage basin for each map sheet surveyed in the program to date in easily used map and table form as an aid to interpretation.

The data was grouped into six generalized rock types for treatment. These are defined in Table 1. The average concentration and standard deviation for 10 elements were compiled for each generalized rock type in each of the 17 map sheets. The 10 elements selected for compilation are zinc, copper, lead, nickel, cobalt, manganese, arsenic, molybdenum, mercury, and uranium. This treatment is similar to an earlier one done as part of a metallogeny study (Sutherland Brown, 1980).

TABLE 1

| GENERALIZED ROCK TYPE | COMPONENT ROCK TYPES |
|---|---|
| Intrusive<br>INTR | Alaskite, granodiorite, granite, quartz diorite, and quartz monzonite. |
| Volcanic<br>VOLC | Agglomerate, andesite, basalt, dacite, greenstone, metavolcanic rocks, olivine basalt, pyroclastic and tuff. |
| Metamorphic<br>METM | Gneiss, phyllite, schist, and slate. |
| Till | Till |
| Sedimentary<br>(Clastic)<br>SEDM | Chert, argillite, siltstone, sandstone, greywacke, conglomerate, quartzite, and metasedimentary rocks. |
| Carbonate<br>CARB | Dolomite and limestone. |

The rock type specified for each sample site represents the dominant rock type underlying the drainage basin of the stream from which the sediment sample was collected.

In the compilation process the analytical data were sorted into the six generalized rock-type groups. The mean element concentration, standard deviation, and the number of samples for each component rock type within each group were then tabulated for each map sheet. These tabulated results were used to calculate the weighted mean and weighted standard deviation of each element concentration for the six generalized rock types in each map sheet.

For example, in map sheet NTS 82K, there were 54 samples taken from sites specified as having dolomite as the predominant underlying component rock type and 23 samples taken from sites having limestone. These were tabulated into the generalized rock type 'carbonate'. The weighted mean element concentration and weighted standard deviation were calculated to give mean and standard deviation results for the carbonate group for map sheet NTS 82K. To continue the example, the 54 samples from dolomitic terrane had a mean concentration for zinc of 61.0 ppm with a standard deviation of 31.3, while the 23 samples from limestone terrane had a mean zinc concentration of 64.2 ppm and a standard deviation of 39.6. These were grouped into the generalized rock-type category of carbonate and the weighted mean zinc concentration in samples of carbonate terrane in map sheet NTS 82K was found to be 62.0 ppm with a weighted standard deviation of 34.0. Each of these values has been tabulated (*see* Tables 2 to 11) and plotted on maps (*see* Figs. 70 to 80).

The formulae used are as follows:

$$\text{weighted mean} = \frac{\Sigma X_i N_i}{\Sigma N_i}$$

$$\text{weighted standard deviation} = \left(\frac{\Sigma S_i^2 (N_i - 1)}{\Sigma (N_i - 1)}\right)^{1/2}$$

where $X_i$ = mean element concentration for component rock type 'i'

$N_i$ = number of samples taken from component rock type 'i'

$S_i$ = standard deviation of results for component rock type 'i'

In the example given above, the calculations involved are as follows:

$X_{DLMT}$ = 61.0 ppm Zn, $S_{DLMT}$ = 31.3, $N_{DLMT}$ = 54

$X_{LMSN}$ = 64.2 ppm Zn, $S_{LMSN}$ = 39.6, $N_{LMSN}$ = 23

$$\text{weighted mean} = \frac{(61.0 \times 54 + 64.2 \times 23)}{(54 + 23)} = 62.0 \text{ ppm Zn}$$

weighted standard deviation =

$$\left[\frac{(31.3 \times 31.3 \times (54 - 1) + 39.6 \times 39.6 \times (23 - 1))}{(54 - 1) + (23 - 1)}\right]^{1/2} = 34.0$$

This same type of calculation was used to determine the overall means and standard deviations for each rock-type group. For example, the average value of zinc in carbonates from all map sheets is 83.5 ppm, the standard deviation is 133, and there was a total of 584 samples. In addition, the mean for each element for all the samples and the corresponding standard deviation were calculated and plotted (*see* Fig. 80).

Portraying the information in this way is intended to assist those doing stream sediment sampling. The mean concentrations give an indication of the background values which might be expected from sediment samples collected from streams draining basins underlain by identified rock types. The standard deviation values give the explorationist an idea of what kind of variation has been experienced in regional sampling and assist in setting threshold values to distinguish anomalies (Levinson, 1974). Given the large variability of element concentrations within any one rock-type group, caution must be exercised in interpreting results. Given this precaution, however, the use of these tabulations and rock-type group averages should facilitate a more efficient screening of anomalous results from stream sediment surveys. For example, a value of 130 ppm zinc in a stream sediment from a predominantly metamorphic terrane in map sheet NTS 82K is not likely to be anomalous since the mean for zinc is 176 ppm. However, if the sample was from a stream draining an area underlain by intrusive rocks where the average zinc concentration is 40 ppm, it would be anomalous.

A genuine local anomaly may not appear to be anomalous when compared to a map sheet average however, and care should be taken not to overlook this possibility. The 1:250 000 map-sheet grid is an artificial one and has no relationship to geological provinces. This must always be kept in mind when averages based on such a grid system are used.

Inevitably, any summarizing of data in this way hides interesting observations to be made in more detailed data listings. The grouping of rock types masks anomalies in specific rock types. Notable examples of this type are the following:

| Element | Map Sheet | No. of Samples | Rock Type | Mean Conc. ppm | S.D. |
|---|---|---|---|---|---|
| Uranium | 104N | 93 | Alaskite | 56.6 | 56.4 |
| Molybdenum | 104O | 45 | Granite | 6.80 | 4.56 |
| Molybdenum | 93A | 104 | Agglomerate | 7.53 | 48.5 |
| Nickel | 104N | 45 | Basalt | 320.00 | 229.00 |
| Cobalt | 104N | 45 | Basalt | 30.9 | 12.8 |

Comparing these examples with the more generalized data in the appropriate tables leads to the following comments. The unusually high uranium in sediments draining terranes underlain by alaskite (intrusive) in NTS 104N is somewhat masked in this compilation (mean uranium is 37.1 ppm). The other intrusive rock type (granite) gives rise to sediments with only 6.91 ppm uranium. Thus, uranium exploration efforts might be more profitably oriented to alaskite rather than granitic terranes in this map sheet. Similarly, in the same map sheet, the nickel concentration of the basaltic sediments is 320 ppm and the cobalt 30.9, as compared to 12.0 ppm and 11.3 ppm respectively in the pyroclastic sediments. The 85 samples of basaltic sediments in NTS 93A gave only 1.09 ppm molybdenum compared to 7.53 ppm in the agglomerates. Molybdenum in sediments from quartz diorite and quartz monzonite terranes in NTS 104O was 3.61 ppm and 2.47 ppm respectively compared to 6.80 ppm found in samples from granitic areas.

The detailed information from which this compilation has been made can be found in a series of releases from the B.C. Ministry of Energy, Mines & Petroleum Resources and the Geological Survey of Canada. They can be ordered from the B.C. Ministry of Energy, Mines & Petroleum Resources in Victoria by referring to the following release numbers:

| Map Sheet | RGS No. | GSC Open File No. |
|---|---|---|
| 82E | | GSC 409 |
| 82F | | GSC 514 |
| 82K | | GSC 515 |
| 82L | | GSC 410 |
| 82M | | GSC 516 |
| 92H | RGS 7 | GSC 865 |
| 92I | RGS 8 | GSC 866 |
| 92J | RGS 9 | GSC 867 |
| 92O | RGS 3 | GSC 774 |
| 92P | RGS 4 | GSC 775 |
| 93A | RGS 5 | GSC 776 |
| 93B | RGS 6 | GSC 777 |
| 103I | RGS 1 | GSC 772 |
| 103P | RGS 2 | GSC 773 |
| 104N | | GSC 517 |
| 104O | | GSC 561 |
| 104P | | GSC 562 |

Results are also available in EBCDIC or ASC11 format on widely compatible magnetic tape (not on cassettes or floppy disks) from the British Columbia Ministry of Energy, Mines and Petroleum Resources in Victoria. All results to date are assembled on magnetic tape.

## ACKNOWLEDGMENTS

I would like to thank A. Panteleyev, W. J. McMillan, G. Ray, T. Hoy, and D. MacIntyre for helpful suggestions on how best to present this data.

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TABLE 2

ELEMENT Zn (ppm)

| ROCK TYPE | INTR | VOLC | METAM | TILL | CARB | SEDM | MAP SHEET AVERAGE |
|---|---|---|---|---|---|---|---|
| MAP SHEET | MEAN MEAN<br>CONC. S.D.<br>NO. SPLS. | MEAN MEAN<br>CONC. S.D.<br>NO. SPLS. | MEAN MEAN<br>CONC. S.D.<br>NO. SPLS. | MEAN MEAN<br>CONC. S.D.<br>NO. SPLS. | MEAN MEAN<br>CONC. S.D.<br>NO. SPLS. | MEAN MEAN<br>CONC. S.D.<br>NO. SPLS. | MEAN MEAN<br>CONC. S.D.<br>NO. SPLS. |
| 82E | 58.1 144<br>729 | 63.3 108<br>313 | 38.5 21.0<br>250 | 41.3 26.9<br>71 |  | 47.8 29.2<br>23 | 54.4 112<br>1543 |
| 82F | 91.9 119<br>485 | 158 148<br>62 | 202 560<br>252 |  |  | 80.5 369<br>439 | 112 349<br>1318 |
| 82K | 40.0 28.8<br>213 | 70.8 60.8<br>30 | 176 730<br>547 | 57.2 35.6<br>116 | 62.0 34.0<br>77 | 99.2 434<br>193 | 119 536<br>1223 |
| 82L | 53.1 25.0<br>170 | 61.8 32.9<br>302 | 64.3 47.3<br>734 | 48.8 26.8<br>81 |  |  | 62.0 43.4<br>1308 |
| 82M | 56.1 24.0<br>83 | 67.3 16.9<br>10 | 57.8 112<br>453 | 56.6 43.5<br>490 |  | 72.5 103<br>115 | 62.7 95.3<br>1150 |
| 92H | 53.0 47.1<br>435 | 85.0 76.4<br>298 |  |  |  | 80.0 48.9<br>134 | 69.7 63.5<br>914 |
| 92I | 58.1 43.0<br>155 | 63.2 21.7<br>273 | 84.8 49.3<br>36 |  |  | 80.0 39.8<br>82 | 66.8 40.3<br>572 |
| 92J | 48.3 52.3<br>431 | 88.0 66.5<br>219 |  |  |  | 67.3 51.1<br>90 | 62.4 58.6<br>780 |
| 920 | 47.7 26.9<br>110 | 55.0 27.3<br>343 |  | 50.2 21.1<br>159 | 56.9 26.6<br>43 | 72.3 31.5<br>228 | 57.8 29.6<br>883 |
| 92P | 41.4 35.1<br>171 | 59.4 50.2<br>447 |  | 50.8 50.6<br>160 | 91.7 63.2<br>25 | 63.7 28.8<br>60 | 55.5 48.2<br>863 |
| 93A | 43.8 25.4<br>64 | 64.9 41.3<br>189 | 75.4 104<br>336 | 59.7 38.9<br>435 | 71.5 70.4<br>94 | 69.1 136<br>89 | 65.7 74.9<br>1220 |
| 93B |  | 42.2 16.5<br>312 |  | 50.1 29.9<br>255 | 60.1 26.1<br>28 | 59.3 37.8<br>39 | 47.1 27.9<br>701 |
| 103I | 43.6 26.0<br>1061 | 79.2 39.8<br>259 | 44.6 23.2<br>417 | 60.1 15.2<br>30 |  | 81.4 56.2<br>357 | 54.7 38.5<br>2124 |
| 103P | 74.2 86.8<br>409 | 134 93.9<br>147 |  |  |  | 136 81.7<br>1213 | 122 87.7<br>1778 |
| 104N | 127 118<br>152 | 89.8 57.6<br>84 |  | 76.3 48.6<br>401 | 84.6 31.3<br>32 | 97.2 77.2<br>189 | 92.0 80.4<br>883 |
| 1040 | 77.8 54.7<br>418 | 91.5 39.1<br>101 | 91.4 73.5<br>93 | 78.1 33.8<br>75 | 129 161<br>26 | 102 93.7<br>161 | 88.8 75.6<br>892 |
| 104P | 50.3 22.1<br>59 | 93.5 60.0<br>145 |  | 66.8 56.0<br>248 | 95.7 185<br>259 | 54.0 54.0<br>64 | 80.0 119<br>801 |
| WEIGHTED MEANS | 60.0 79.2 | 72.0 60.0 | 91.6 350 | 59.9 41.6 | 83.5 133 | 100 180 | 76.5 178 |
| TOTAL SPLS | 5145 | 3534 | 3118 | 2521 | 584 | 3476 | 18953 |

TABLE 3

ELEMENT Cu (ppm)

| ROCK TYPE | INTR | VOLC | METAM | TILL | CARB | SEDM | MAP SHEET AVERAGE |
|---|---|---|---|---|---|---|---|
| MAP SHEET | MEAN MEAN<br>CONC. S.D.<br>NO. SPLS. | MEAN MEAN<br>CONC. S.D.<br>NO. SPLS. | MEAN MEAN<br>CONC. S.D.<br>NO. SPLS. | MEAN MEAN<br>CONC. S.D.<br>NO. SPLS. | MEAN MEAN<br>CONC. S.D.<br>NO. SPLS. | MEAN MEAN<br>CONC. S.D.<br>NO. SPLS. | MEAN MEAN<br>CONC. S.D.<br>NO. SPLS. |
| 82E | 19.1 70.8<br>729 | 37.1 61.1<br>313 | 14.5 15.7<br>250 | 24.2 45.3<br>71 | | 37.9 86.4<br>23 | 22.2 59.0<br>1543 |
| 82F | 14.4 20.3<br>485 | 54.5 32.6<br>62 | 25.4 22.1<br>252 | | | 23.8 21.5<br>439 | 22.1 23.4<br>1318 |
| 82K | 10.7 10.2<br>213 | 41.7 34.2<br>30 | 38.8 22.5<br>547 | 17.9 11.1<br>116 | 23.4 10.5<br>77 | 26.7 15.2<br>193 | 28.6 21.7<br>1223 |
| 82L | 16.4 14.5<br>170 | 27.4 23.9<br>302 | 23.4 15.4<br>734 | 19.9 12.8<br>81 | | | 23.3 19.0<br>1308 |
| 82M | 18.3 13.6<br>83 | 14.5 7.8<br>10 | 22.3 21.0<br>452 | 24.1 18.7<br>489 | | 32.1 13.6<br>115 | 23.7 20.0<br>1150 |
| 92H | 21.5 23.7<br>435 | 45.6 69.5<br>298 | | | | 35.4 72.2<br>134 | 31.9 52.3<br>914 |
| 92I | 57.5 95.7<br>155 | 35.2 18.6<br>273 | 52.2 46.3<br>36 | | | 33.3 14.6<br>82 | 42.0 54.2<br>572 |
| 92J | 25.4 18.9<br>431 | 52.7 46.8<br>219 | | | | 33.6 16.2<br>90 | 34.4 31.2<br>780 |
| 92O | 50.2 122<br>110 | 27.8 27.5<br>343 | | 22.5 12.6<br>159 | 25.5 14.7<br>43 | 35.0 31.7<br>228 | 31.4 50.2<br>883 |
| 92P | 25.0 28.4<br>171 | 91.6 23.9<br>447 | | 19.2 17.1<br>160 | 27.6 21.1<br>25 | 38.9 19.8<br>60 | 27.5 25.3<br>863 |
| 93A | 25.2 20.3<br>64 | 35.7 25.3<br>189 | 24.3 12.8<br>336 | 28.8 20.6<br>435 | 30.6 17.8<br>94 | 30.9 15.3<br>89 | 28.7 20.2<br>1220 |
| 93B | | 18.0 13.2<br>312 | | 21.7 13.5<br>255 | 27.4 16.5<br>28 | 25.0 10.8<br>39 | 20.5 13.9<br>701 |
| 103I | 19.9 19.2<br>1061 | 56.0 41.8<br>259 | 24.5 14.5<br>417 | 19.5 7.3<br>30 | | 32.5 22.0<br>357 | 27.3 25.9<br>2124 |
| 103P | 20.4 18.1<br>409 | 89.6 184<br>147 | | | | 46.9 22.4<br>1213 | 44.3 58.9<br>1776 |
| 104N | 24.5 30.4<br>152 | 34.5 22.4<br>84 | | 29.1 21.4<br>401 | 43.4 20.5<br>32 | 45.8 26.7<br>189 | 33.8 27.9<br>883 |
| 104O | 17.8 15.4<br>418 | 31.8 26.6<br>101 | 39.7 33.1<br>93 | 21.5 13.9<br>75 | 40.3 55.2<br>26 | 40.1 31.2<br>161 | 27.1 29.8<br>892 |
| 104P | 11.4 8.6<br>59 | 53.0 35.0<br>145 | | 14.9 10.3<br>248 | 19.7 17.6<br>259 | 16.3 8.0<br>64 | 23.8 24.5<br>801 |
| WEIGHTED MEANS | 21.3 40.2 | 46.3 52.8 | 26.5 19.2 | 23.6 18.6 | 25.3 20.2 | 37.2 27.0 | 28.8 36.6 |
| TOTAL SPLS | 5145 | 3534 | 3117 | 2520 | 584 | 3476 | 18953 |

TABLE 4

ELEMENT Pb (ppm)

| ROCK TYPE | INTR | VOLC | METAM | TILL | CARB | SEDM | MAP SHEET AVERAGE |
|---|---|---|---|---|---|---|---|
| MAP SHEET | MEAN MEAN CONC. S.D. NO. SPLS. | MEAN MEAN CONC. S.D. NO. SPLS. | MEAN MEAN CONC. S.D. NO. SPLS. | MEAN MEAN CONC. S.D. NO. SPLS. | MEAN MEAN CONC. S.D. NO. SPLS. | MEAN MEAN CONC. S.D. NO. SPLS. | MEAN MEAN CONC. S.D. NO. SPLS. |
| 82E | 7.18 9.71<br>729 | 9.73 45.2<br>313 | 5.01 6.46<br>250 | 4.39 4.32<br>71 | | 7.30 6.53<br>23 | 7.77 22.3<br>1543 |
| 82F | 24.9 45.3<br>485 | 43.9 73.8<br>62 | 43.5 139<br>245 | | | 21.7 115<br>439 | 28.0 97.2<br>1318 |
| 82K | 10.4 8.43<br>213 | 12.1 9.8<br>30 | 51.0 167<br>547 | 13.7 24.2<br>116 | 20.4 25.3<br>77 | 29.8 22.1<br>193 | 34.2 191<br>1223 |
| 82L | 4.86 5.55<br>170 | 3.83 3.18<br>302 | 5.56 6.89<br>734 | 3.84 3.88<br>81 | | | 5.08 6.50<br>1308 |
| 82M | 7.94 8.70<br>83 | 4.90 3.90<br>10 | 13.0 62.9<br>451 | 8.19 10.2<br>489 | | 13.2 17.2<br>115 | 10.5 41.1<br>1149 |
| 92H | 4.70 8.23<br>435 | 7.19 31,8<br>298 | | | | 6.89 7.65<br>134 | 5.91 19.4<br>914 |
| 92I | 4.65 29.2<br>155 | 2.67 2.78<br>273 | 3.19 4.08<br>36 | | | 3.23 2.86<br>82 | 3.35 15.4<br>572 |
| 92J | 4.29 20.6<br>431 | 6.35 18.2<br>219 | | | | 2.98 10.4<br>90 | 4.70 18.6<br>778 |
| 920 | 5.65 12.4<br>110 | 2.78 3.98<br>343 | | 2.23 2.27<br>159 | 2.05 1.40<br>43 | 3.24 2.80<br>228 | 3.13 5.41<br>883 |
| 92P | 4.35 4.95<br>171 | 5.25 24.2<br>447 | | 2.90 2.58<br>160 | 2.16 1.49<br>25 | 5.08 3.98<br>60 | 4.53 17.6<br>863 |
| 93A | 5.20 6.24<br>64 | 2.90 2.90<br>189 | 8.66 21.0<br>336 | 4.90 11.4<br>435 | 14.5 8.03<br>94 | 14.6 6.86<br>89 | 7.05 13.9<br>1220 |
| 93B | | 1.41 1.06<br>312 | | 1.40 1.10<br>255 | 1.00 1.00<br>28 | 1.33 0.74<br>39 | 1.42 1.03<br>701 |
| 103I | 2.59 4.7<br>1061 | 6.27 8.78<br>259 | 1.45 1.48<br>417 | 3.17 2.15<br>30 | | 6.11 8.49<br>357 | 3.41 6.14<br>2124 |
| 103P | 7.79 17.0<br>409 | 21.8 42.3<br>147 | | | | 9.70 9.80<br>1213 | 10.3 17.1<br>1778 |
| 104N | 20.9 53.1<br>152 | 6.76 11.4<br>84 | | 4.58 7.79<br>401 | 2.88 1.86<br>32 | 4.76 5.47<br>189 | 7.71 23.9<br>883 |
| 1040 | 10.2 21.4<br>418 | 5.52 8.06<br>101 | 6.06 7.33<br>93 | 2.40 1.94<br>75 | 8.15 10.76<br>26 | 7.85 19.9<br>161 | 8.36 18.4<br>892 |
| 104P | 6.95 5.44<br>59 | 7.57 5.67<br>145 | | 6.42 13.3<br>248 | 14.8 39.7<br>259 | 6.08 4.41<br>64 | 9.49 24.7<br>801 |
| WEIGHTED MEANS | 8.0 20.8 | 6.49 23.4 | 17.4 84.1 | 5.25 9.94 | 12.4 28.4 | 10.8 42.2 | 9.72 57.6 |
| TOTAL SPLS | 5145 | 3534 | 3109 | 2520 | 584 | 3476 | 18950 |

## TABLE 5

ELEMENT NI (ppm)

| ROCK TYPE | INTR | VOLC | METAM | TILL | CARB | SEDM | MAP SHEET AVERAGE |
|---|---|---|---|---|---|---|---|
| MAP SHEET | MEAN CONC. MEAN S.D.<br>NO. SPLS. | MEAN CONC. MEAN S.D.<br>NO. SPLS. | MEAN CONC. MEAN S.D.<br>NO. SPLS. | MEAN CONC. MEAN S.D.<br>NO. SPLS. | MEAN CONC. MEAN S.D.<br>NO. SPLS. | MEAN CONC. MEAN S.D.<br>NO. SPLS. | MEAN CONC. MEAN S.D.<br>NO. SPLS. |
| 82E | 9.78 12.4<br>729 | 20.8 25.4<br>313 | 9.53 6.24<br>250 | 10.9 11.6<br>71 |  | 11.4 10.3<br>23 | 13.0 20.0<br>1543 |
| 82F | 13.8 18.4<br>485 | 28.4 43.5<br>62 | 29.4 35.4<br>252 |  |  | 12.0 8.48<br>439 | 17.5 24.4<br>1318 |
| 82K | 10.1 15.6<br>213 | 27.7 25.4<br>30 | 37.1 28.6<br>547 | 13.9 8.26<br>116 | 18.2 8.84<br>77 | 16.7 10.7<br>193 | 25.1 24.7<br>1223 |
| 82L | 15.9 14.9<br>170 | 23.2 21.6<br>302 | 22.5 17.6<br>734 | 18.8 15.6<br>81 |  |  | 21.7 18.4<br>1308 |
| 82M | 12.6 10.4<br>83 | 35.2 19.2<br>10 | 17.9 12.8<br>452 | 20.1 14.2<br>489 |  | 28.4 12.1<br>115 | 19.6 14.5<br>1150 |
| 92H | 14.0 22.5<br>435 | 24.9 25.2<br>298 |  |  |  | 15.0 9.60<br>134 | 19.5 33.7<br>914 |
| 92I | 24.2 56.1<br>155 | 34.7 34.2<br>273 | 89.1 137<br>36 |  |  | 31.8 30.8<br>82 | 36.5 66.6<br>572 |
| 92J | 19.2 71.4<br>431 | 75.5 110<br>219 |  |  |  | 60.0 110<br>90 | 50.2 127<br>780 |
| 92O | 101 359<br>110 | 34.5 25.6<br>343 |  | 26.8 20.0<br>159 | 58.7 27.1<br>43 | 84.8 224<br>228 | 55.5 173<br>883 |
| 92P | 27.5 42.7<br>171 | 31.4 25.7<br>447 |  | 22.4 17.1<br>160 | 60.4 86.1<br>25 | 28.8 34.4<br>60 | 29.6 33.0<br>863 |
| 93A | 19.5 13.8<br>64 | 41.5 35.6<br>189 | 28.5 20.5<br>336 | 36.6 47.1<br>435 | 29 12.8<br>94 | 27.9 16.1<br>89 | 33.7 35.8<br>1220 |
| 93B |  | 30.7 22.3<br>312 |  | 32.9 22.6<br>255 | 41.3 29.9<br>28 | 30.9 20.7<br>39 | 31.2 22.1<br>701 |
| 103I | 7.99 8.22<br>1061 | 14.9 8.5<br>259 | 10.8 6.88<br>417 | 14.7 4.85<br>30 |  | 16.6 13.9<br>357 | 10.9 9.97<br>2124 |
| 103P | 15.8 16.0<br>409 | 26.4 20.1<br>147 |  |  |  | 65.6 38.1<br>1213 | 50.8 39.6<br>1778 |
| 104N | 39.9 84.5<br>152 | 177 169<br>84 |  | 48.8 72.3<br>401 | 54.7 66.7<br>32 | 86.4 144<br>189 | 71.6 128<br>883 |
| 104O | 18.2 17.2<br>418 | 51.3 76.4<br>101 | 33.7 21.5<br>93 | 31.3 20.8<br>75 | 34.4 17.9<br>26 | 39.3 106<br>161 | 29.2 55.2<br>892 |
| 104P | 12.5 7.51<br>59 | 100 193<br>145 |  | 31.1 70.0<br>248 | 28.6 38.7<br>259 | 21.5 20.8<br>64 | 44.9 115<br>801 |
| WEIGHTED MEANS | 16.4 60.9 | 38.3 60.6 | 24.1 24.9 | 30.1 43.2 | 33.2 37.0 | 45.0 76.6 | 30.5 64.6 |
| TOTAL SPLS | 5145 | 3534 | 3117 | 2520 | 584 | 3476 | 18953 |

## TABLE 6

ELEMENT Co (ppm)

| ROCK TYPE | INTR | VOLC | METAM | TILL | CARB | SEDM | MAP SHEET AVERAGE |
|---|---|---|---|---|---|---|---|
| MAP SHEET | MEAN CONC. MEAN S.D.<br>NO. SPLS. | MEAN CONC. MEAN S.D.<br>NO. SPLS. | MEAN CONC. MEAN S.D.<br>NO. SPLS. | MEAN CONC. MEAN S.D.<br>NO. SPLS. | MEAN CONC. MEAN S.D.<br>NO. SPLS. | MEAN CONC. MEAN S.D.<br>NO. SPLS. | MEAN CONC. MEAN S.D.<br>NO. SPLS. |
| 82E | 5.18 2.66<br>729 | 7.54 4.72<br>313 | 5.30 2.21<br>250 | 5.42 3.02<br>71 |  | 6.09 3.26<br>23 | 5.90 3.62<br>1543 |
| 82F | 6.20 3.43<br>485 | 13.8 6.21<br>62 | 10.2 6.48<br>252 |  |  | 9.45 6.62<br>439 | 8.69 6.00<br>1318 |
| 82K | 4.45 3.89<br>213 | 12.3 9.81<br>30 | 15.4 7.49<br>547 | 7.97 4.67<br>116 | 10.6 5.06<br>77 | 11.6 6.88<br>193 | 11.7 7.88<br>1223 |
| 82L | 7.21 3.52<br>170 | 9.83 4.99<br>302 | 9.01 4.68<br>734 | 8.06 3.93<br>81 |  |  | 8.96 4.71<br>1308 |
| 82M | 8.53 4.74<br>83 | 17.2 8.04<br>10 | 9.46 4.69<br>452 | 10.0 5.91<br>489 |  | 13.6 4.05<br>116 | 10.0 5.74<br>1150 |
| 92H | 6.00 3.85<br>435 | 10.9 5.77<br>298 |  |  |  | 10.3 11.6<br>134 | 8.55 7.14<br>914 |
| 92I | 8.63 4.74<br>155 | 11.3 4.14<br>273 | 15.9 8.12<br>36 |  |  | 10.7 4.30<br>82 | 10.8 5.40<br>572 |
| 92J | 7.15 5.49<br>431 | 15.9 8.85<br>219 |  |  |  | 12.2 6.80<br>90 | 10.9 9.17<br>780 |
| 92O | 12.6 14.5<br>110 | 12.4 4.77<br>343 |  | 12.1 11.4<br>159 | 13.9 4.78<br>43 | 15.3 9.00<br>228 | 13.2 9.06<br>883 |
| 92P | 8.51 4.26<br>171 | 12.1 6.84<br>447 |  | 8.77 4.12<br>160 | 12.6 7.23<br>25 | 11.9 5.43<br>60 | 10.8 6.12<br>863 |
| 93A | 9.02 5.15<br>64 | 11.9 9.04<br>189 | 11.8 9.22<br>336 | 10.8 5.20<br>435 | 13.7 6.78<br>94 | 11.0 6.69<br>89 | 11.4 7.44<br>1220 |
| 93B |  | 9.52 5.60<br>312 |  | 9.62 6.76<br>255 | 9.93 4.38<br>28 | 10.5 3.37<br>39 | 9.69 6.07<br>701 |
| 103I | 7.47 6.20<br>1061 | 13.0 5.21<br>259 | 8.43 3.65<br>417 | 8.37 2.79<br>30 |  | 11.5 5.10<br>357 | 9.03 5.87<br>2124 |
| 103P | 9.85 5.35<br>409 | 16.1 7.37<br>147 |  |  |  | 19.6 13.7<br>1213 | 17.0 12.5<br>1778 |
| 104N | 6.97 6.77<br>152 | 21.8 9.94<br>84 |  | 10.1 6.98<br>401 | 11.8 5.83<br>32 | 15.0 11.1<br>189 | 12.1 10.0<br>883 |
| 104O | 7.78 5.45<br>418 | 16.0 10.8<br>101 | 11.8 7.10<br>93 | 10.9 6.10<br>75 | 12.7 10.2<br>26 | 11.0 8.29<br>161 | 10.1 7.79<br>892 |
| 104P | 5.58 2.63<br>59 | 17.2 12.5<br>145 |  | 7.50 6.09<br>248 | 8.66 4.56<br>259 | 9.33 3.03<br>64 | 9.99 8.46<br>801 |
| WEIGHTED MEANS | 7.13 5.24 | 12.2 6.80 | 10.4 5.93 | 9.65 6.30 | 10.7 5.58 | 14.4 10.0 | 10.5 7.58 |
| TOTAL SPLS | 5145 | 3534 | 3117 | 2520 | 584 | 3476 | 18953 |

## TABLE 7

ELEMENT Mn (ppm)

| ROCK TYPE | INTR | VOLC | METAM | TILL | CARB | SEDM | MAP SHEET AVERAGE |
|---|---|---|---|---|---|---|---|
| MAP SHEET | MEAN MEAN<br>CONC. S.D.<br>NO. SPLS. | MEAN MEAN<br>CONC. S.D.<br>NO. SPLS. | MEAN MEAN<br>CONC. S.D.<br>NO. SPLS. | MEAN MEAN<br>CONC. S.D.<br>NO. SPLS. | MEAN MEAN<br>CONC. S.D.<br>NO. SPLS. | MEAN MEAN<br>CONC. S.D.<br>NO. SPLS. | MEAN MEAN<br>CONC. S.D.<br>NO. SPLS. |
| 82E | 430 405<br>729 | 509 701<br>313 | 410 464<br>250 | 360 254<br>71 | | 576 851<br>23 | 448 541<br>1543 |
| 82F | 440 260<br>485 | 604 253<br>62 | 501 484<br>252 | | | 438 282<br>439 | 461 302<br>1318 |
| 82K | 274 220<br>213 | 490 334<br>30 | 564 416<br>547 | 470 870<br>116 | 546 943<br>77 | 275 339<br>193 | 492 518<br>1223 |
| 82L | 565 543<br>170 | 564 514<br>302 | 406 395<br>734 | 490 545<br>81 | | | 470 461<br>1308 |
| 82M | 432 179<br>83 | 593 489<br>10 | 473 1141<br>452 | 405 405<br>489 | | 453 364<br>115 | 440 783<br>1150 |
| 92H | 386 547<br>435 | 600 562<br>298 | | | | 516 300<br>134 | 484 527<br>914 |
| 92I | 506 610<br>155 | 639 938<br>273 | 447 212<br>36 | | | 666 868<br>82 | 588 800<br>572 |
| 92J | 263 358<br>431 | 513 270<br>219 | | | | 368 204<br>90 | 356 341<br>780 |
| 920 | 497 760<br>110 | 771 1638<br>343 | | 1150 3660<br>159 | 568 417<br>43 | 674 620<br>228 | 771 1910<br>883 |
| 92P | 838 881<br>171 | 857 1290<br>447 | | 773 1440<br>160 | 617 770<br>25 | 764 640<br>60 | 825 1200<br>863 |
| 93A | 599 570<br>64 | 1046 2094<br>189 | 447 385<br>336 | 738 836<br>435 | 438 325<br>94 | 754 2330<br>89 | 695 1330<br>1220 |
| 93B | | 913 1750<br>312 | | 818 1540<br>255 | 1830 4980<br>28 | 836 1730<br>39 | 928 1900<br>701 |
| 103I | 407 709<br>1061 | 852 503<br>259 | 314 201<br>417 | 670 382<br>30 | | 675 470<br>357 | 492 606<br>2124 |
| 103P | 538 378<br>409 | 913 552<br>147 | | | | 1710 3190<br>1213 | 1380 2700<br>1776 |
| 104N | 556 1094<br>152 | 857 768<br>84 | | 732 1200<br>401 | 744 688<br>32 | 1033 5231<br>189 | 807 2770<br>883 |
| 1040 | 498 799<br>418 | 1155 2600<br>101 | 936 2628<br>93 | 822 841<br>75 | 733 599<br>26 | 787 1490<br>161 | 701 1510<br>892 |
| 104P | 362 281<br>59 | 634 314<br>145 | | 407 468<br>248 | 443 551<br>259 | 292 134<br>64 | 449 456<br>801 |
| WEIGHTED MEANS | 443 578 | 741 1178 | 460 720 | 647 1299 | 568 1229 | 985 2330 | 642 1348 |
| TOTAL SPLS | 5145 | 3534 | 3117 | 2520 | 584 | 3476 | 18951 |

TABLE 8

ELEMENT As (ppm)

| ROCK TYPE | INTR | VOLC | METAM | TILL | CARB | SEDM | MAP SHEET AVERAGE |
|---|---|---|---|---|---|---|---|
| MAP SHEET | MEAN MEAN CONC. S.D. NO. SPLS. | MEAN MEAN CONC. S.D. NO. SPLS. | MEAN MEAN CONC. S.D. NO. SPLS. | MEAN MEAN CONC. S.D. NO. SPLS. | MEAN MEAN CONC. S.D. NO. SPLS. | MEAN MEAN CONC. S.D. NO. SPLS. | MEAN MEAN CONC. S.D. NO. SPLS. |
| 82E | | | | | | | |
| 82F | | | | | | | |
| 82K | | | | | | | |
| 82L | | | | | | | |
| 82M | | | | | | | |
| 92H | 7.82 48.6<br>435 | 10.9 19.0<br>298 | | | | 13.3 33.1<br>134 | 9.98 37.9<br>914 |
| 92I | 6.55 18.2<br>155 | 4.09 14.6<br>273 | 30.0 32.1<br>36 | | | 7.05 6.23<br>82 | 7.05 14.8<br>572 |
| 92J | 6.06 16.3<br>431 | 25.1 45.0<br>219 | | | | 11.8 14.8<br>90 | 12.3 29.4<br>780 |
| 92O | 7.49 11.7<br>110 | 6.04 14.9<br>343 | | 5.54 9.58<br>159 | 1.62 1.48<br>43 | 9.46 19.4<br>228 | 6.79 15.0<br>883 |
| 92P | 1.96 5.61<br>171 | 4.01 10.5<br>447 | | 2.37 6.46<br>160 | 1.3 0.72<br>25 | 5.46 6.60<br>60 | 3.32 8.90<br>863 |
| 93A | 4.09 4.5<br>64 | 8.56 18.7<br>189 | 5.79 41.3<br>336 | 5.78 8.68<br>435 | 7.86 8.01<br>94 | 5.34 6.40<br>89 | 6.24 23.8<br>1220 |
| 93B | | 2.69 6.8<br>312 | | 4.23 9.37<br>255 | 4.25 2.95<br>28 | 5.99 7.20<br>39 | 3.64 7.72<br>701 |
| 103I | 1.12 2.45<br>1061 | 2.93 5.1<br>259 | 0.73 0.64<br>417 | 3.02 2.06<br>30 | | 9.72 13.6<br>357 | 2.74 7.45<br>2124 |
| 103P | 5.33 13.5<br>409 | 21.4 23.5<br>147 | | | | 15.7 28.6<br>1213 | 13.8 25.9<br>1778 |
| 104N | | | | | | | |
| 104O | | | | | | | |
| 104P | | | | | | | |
| WEIGHTED MEANS | 4.17 21.3 | 8.07 19.0 | 4.22 27.8 | 4.76 8.59 | 5.05 5.81 | 12.7 24.0 | 7.34 21.2 |
| TOTAL SPLS | 2836 | 2487 | 789 | 1039 | 190 | 2292 | 9835 |

TABLE 9

ELEMENT Mo (ppm)

| ROCK TYPE | INTR | VOLC | METAM | TILL | CARB | SEDM | MAP SHEET AVERAGE |
|---|---|---|---|---|---|---|---|
| MAP SHEET | MEAN MEAN<br>CONC. S.D.<br>NO. SPLS. | MEAN MEAN<br>CONC. S.D.<br>NO. SPLS. | MEAN MEAN<br>CONC. S.D.<br>NO. SPLS. | MEAN MEAN<br>CONC. S.D.<br>NO. SPLS. | MEAN MEAN<br>CONC. S.D.<br>NO. SPLS. | MEAN MEAN<br>CONC. S.D.<br>NO. SPLS. | MEAN MEAN<br>CONC. S.D.<br>NO. SPLS. |
| 82E | 2.01 4.77<br>729 | 2.05 3.87<br>313 | 1.28 0.92<br>250 | 1.61 1.57<br>71 | | 1.26 0.69<br>23 | 1.82 3.78<br>1543 |
| 82F | 1.60 1.32<br>485 | 2.05 2.66<br>62 | 1.76 1.33<br>252 | | | 1.50 2.26<br>439 | 1.61 1.79<br>1318 |
| 82K | 1.88 3.33<br>213 | 1.40 1.19<br>30 | 1.86 1.60<br>547 | 1.56 0.95<br>116 | 1.63 0.85<br>77 | 1.72 2.74<br>193 | 1.77 2.18<br>1223 |
| 82L | 1.99 2.96<br>170 | 1.66 1.59<br>302 | 1.68 1.22<br>734 | 1.57 1.05<br>81 | | | 1.79 1.75<br>1308 |
| 82M | 1.94 1.66<br>83 | 1.40 0.84<br>10 | 2.08 7.27<br>452 | 1.56 1.13<br>489 | | 1.50 0.88<br>115 | 1.79 4.65<br>1150 |
| 92H | 1.45 1.27<br>435 | 1.72 1.28<br>298 | | | | 1.54 2.28<br>134 | 1.58 1.49<br>914 |
| 92I | 1.46 1.38<br>155 | 1.40 0.81<br>273 | 2.61 3.62<br>36 | | | 1.34 1.20<br>82 | 1.59 1.48<br>572 |
| 92J | 1.61 2.15<br>431 | 2.11 2.63<br>219 | | | | 1.79 1.74<br>90 | 1.76 2.22<br>780 |
| 920 | 2.32 7.92<br>110 | 1.22 0.89<br>343 | | 1.08 0.46<br>159 | 1.47 1.08<br>43 | 1.21 0.69<br>228 | 1.34 2.90<br>883 |
| 92P | 2.47 5.51<br>171 | 1.62 3.14<br>446 | | 1.32 1.23<br>160 | 1.40 0.82<br>25 | 1.47 1.02<br>60 | 1.72 3.42<br>862 |
| 93A | 1.14 0.66<br>64 | 4.63 36.0<br>189 | 1.49 2.47<br>336 | 1.89 9.97<br>435 | 1.17 0.56<br>94 | 1.16 0.74<br>89 | 2.06 15.5<br>1220 |
| 93B | | 1.12 0.52<br>312 | | 1.18 0.68<br>255 | 1.32 0.82<br>28 | 1.08 0.35<br>39 | 1.15 0.69<br>702 |
| 103I | 1.51 3.93<br>1061 | 2.02 5.24<br>259 | 1.48 1.17<br>417 | 1.33 0.71<br>30 | | 2.20 3.19<br>357 | 1.68 3.62<br>2124 |
| 103P | 3.07 10.6<br>409 | 2.96 3.35<br>147 | | | | 2.30 8.30<br>1213 | 2.53 8.60<br>1778 |
| 104N | 2.56 2.79<br>152 | 1.60 1.17<br>84 | | 2.05 3.67<br>401 | 2.31 1.20<br>32 | 2.27 1.81<br>189 | 2.20 3.28<br>883 |
| 1040 | 3.03 3.85<br>418 | 1.68 1.80<br>101 | 2.73 5.95<br>93 | 1.67 2.35<br>75 | 2.58 3.18<br>26 | 2.12 1.71<br>161 | 2.53 3.66<br>892 |
| 104P | 3.07 3.19<br>59 | 2.03 2.64<br>145 | | 1.61 2.07<br>248 | 2.53 4.72<br>259 | 1.56 2.44<br>64 | 2.13 3.47<br>801 |
| WEIGHTED MEANS | 1.97 4.56 | 1.87 8.71 | 1.74 3.27 | 1.62 4.53 | 2.00 3.28 | 1.91 5.20 | 1.86 5.48 |
| TOTAL SPLS | 5145 | 3533 | 3117 | 2520 | 584 | 3476 | 18953 |

TABLE 10

ELEMENT Hg (ppb)

| ROCK TYPE | INTR | VOLC | METAM | TILL | CARB | SEDM | MAP SHEET AVERAGE |
|---|---|---|---|---|---|---|---|
| MAP SHEET | MEAN MEAN CONC. S.D. NO. SPLS. | MEAN MEAN CONC. S.D. NO. SPLS. | MEAN MEAN CONC. S.D. NO. SPLS. | MEAN MEAN CONC. S.D. NO. SPLS. | MEAN MEAN CONC. S.D. NO. SPLS. | MEAN MEAN CONC. S.D. NO. SPLS. | MEAN MEAN CONC. S.D. NO. SPLS. |
| 82E | | | | | | | |
| 82F | 28.2 37.8<br>484 | 79.0 252<br>62 | 30.2 37.1<br>252 | | | 27.2 26.6<br>439 | 30.6 65.2<br>1317 |
| 82K | 17.0 15.4<br>210 | 17.5 10.5<br>30 | 25.2 27.7<br>547 | 25.6 30.0<br>114 | 46.7 57.9<br>77 | 22.9 29.1<br>193 | 26.6 59.3<br>1218 |
| 82L | | | | | | | |
| 82M | 14.0 11.1<br>15 | | 16.2 15.2<br>108 | 15.4 13.0<br>236 | | 13.6 8.59<br>84 | 15.2 12.8<br>443 |
| 92H | 66.6 245<br>432 | 75.6 165<br>297 | | | | 104 321<br>133 | 76.3 232<br>908 |
| 92I | 43.9 28.7<br>153 | 57.3 60.9<br>273 | 38.9 37.0<br>36 | | | 58.4 42.2<br>82 | 52.0 49.1<br>570 |
| 92J | 20.1 25.4<br>429 | 66.2 179<br>219 | | | | 156 902<br>90 | 49.6 305<br>778 |
| 92O | 144 567<br>110 | 107 123<br>342 | | 93.4 90.1<br>158 | 79.5 66.5<br>43 | 241 656<br>228 | 142 402<br>881 |
| 92P | 81.7 36.1<br>169 | 82.1 74.0<br>445 | | 72.9 34.2<br>160 | 56.4 20.6<br>25 | 109 32.9<br>60 | 81.4 59.5<br>859 |
| 93A | 49.5 22.8<br>65 | 64.3 40.7<br>189 | 41.3 23.0<br>336 | 70.6 168<br>436 | 44.3 21.2<br>94 | 39.0 24.2<br>89 | 56.4 104<br>1222 |
| 93B | | 53.3 43.4<br>309 | | 58.0 35.1<br>254 | 58.6 32.3<br>23 | 57.9 34.7<br>39 | 56.8 38.6<br>697 |
| 103I | 29.2 43.2<br>1061 | 31.0 49.0<br>259 | 20.7 15.1<br>417 | 37.0 25.5<br>30 | | 38.1 31.4<br>357 | 29.6 38.5<br>2124 |
| 103P | 34.6 27.7<br>409 | 109 177<br>146 | | | | 105 63.0<br>1212 | 88.9 79.0<br>1776 |
| 104N | 29.0 22.2<br>151 | 86.7 140<br>83 | | 43.0 38.2<br>400 | 75.0 57.9<br>30 | 119 456<br>189 | 62.2 223<br>878 |
| 104O | | | | | | | |
| 104P | | | | | | | |
| WEIGHTED MEANS | 39.0 133 | 71.9 115 | 27.7 25.6 | 54.1 91.0 | 55.5 46.0 | 87.9 259 | 58.2 160 |
| TOTAL SPLS | 3688 | 2654 | 1696 | 1788 | 297 | 3195 | 13671 |

## TABLE 11

ELEMENT U (ppm)

| ROCK TYPE | INTR | VOLC | METAM | TILL | CARB | SEDM | MAP SHEET AVERAGE |
|---|---|---|---|---|---|---|---|
| MAP SHEET | MEAN MEAN<br>CONC. S.D.<br>NO. SPLS. | MEAN MEAN<br>CONC. S.D.<br>NO. SPLS. | MEAN MEAN<br>CONC. S.D.<br>NO. SPLS. | MEAN MEAN<br>CONC. S.D.<br>NO. SPLS. | MEAN MEAN<br>CONC. S.D.<br>NO. SPLS. | MEAN MEAN<br>CONC. S.D.<br>NO. SPLS. | MEAN MEAN<br>CONC. S.D.<br>NO. SPLS. |
| 82E | 11.9 18.2<br>729 | 5.69 6.72<br>313 | 7.97 8.61<br>250 | 7.07 6.48<br>71 | | 5.71 2.68<br>23 | 10.2 17.7<br>1544 |
| 82F | 23.0 37.6<br>485 | 3.44 2.21<br>62 | 7.43 8.76<br>253 | | | 7.54 13.8<br>439 | 13.7 27.6<br>1318 |
| 82K | 20.6 38.9<br>213 | 4.51 6.70<br>30 | 7.02 14.7<br>548 | 6.77 15.0<br>116 | 4.91 8.44<br>77 | 6.80 11.6<br>193 | 8.99 21.2<br>1224 |
| 82L | 6.92 7.23<br>170 | 3.57 8.89<br>302 | 7.67 5.93<br>734 | 5.48 5.12<br>81 | | | 6.48 7.33<br>1308 |
| 82M | 18.3 20.4<br>83 | 4.91 2.12<br>10 | 10.2 12.1<br>453 | 8.27 7.29<br>490 | | 5.58 5.18<br>115 | 9.44 11.2<br>1152 |
| 92H | 4.75 8.90<br>393 | 2.45 5.49<br>225 | | | | 1.80 0.75<br>113 | 3.50 7.15<br>767 |
| 92I | 3.61 4.80<br>155 | 1.69 1.06<br>273 | 1.99 0.97<br>36 | | | 2.05 0.97<br>82 | 2.28 2.77<br>572 |
| 92J | 3.76 6.03<br>429 | 2.28 2.59<br>219 | | | | 2.84 5.52<br>90 | 3.15 5.10<br>778 |
| 92O | 3.23 4.31<br>109 | 1.78 1.48<br>343 | | 1.67 1.09<br>159 | 1.28 0.91<br>43 | 1.53 0.79<br>227 | 1.85 1.96<br>881 |
| 92P | 6.31 7.14<br>171 | 2.97 4.04<br>447 | | 2.86 2.29<br>160 | 1.58 0.51<br>25 | 2.30 1.49<br>60 | 3.53 4.60<br>863 |
| 93A | 4.74 5.05<br>64 | 2.62 1.70<br>189 | 6.86 5.02<br>336 | 2.96 1.90<br>436 | 4.54 1.78<br>94 | 5.85 2.67<br>89 | 4.40 3.73<br>1221 |
| 93B | | 2.65 2.53<br>310 | | 2.41 1.53<br>257 | 2.27 2.66<br>28 | 1.92 0.87<br>39 | 2.59 2.10<br>703 |
| 103I | 5.60 7.68<br>1061 | 2.89 2.94<br>259 | 3.59 2.53<br>417 | 2.97 1.50<br>30 | | 2.98 2.12<br>357 | 4.40 5.84<br>2124 |
| 103P | 10.3 9.62<br>404 | 3.64 3.98<br>146 | | | | 1.60 2.14<br>1208 | 3.77 6.21<br>1767 |
| 104N | 37.1 44.3<br>152 | 2.85 1.68<br>83 | | 8.17 16.0<br>401 | 2.09 0.73<br>32 | 4.36 14.2<br>190 | 11.4 27.2<br>883 |
| 104O | 16.6 18.9<br>418 | 6.61 11.4<br>101 | 6.49 11.7<br>93 | 3.90 2.70<br>75 | 5.52 5.48<br>26 | 5.23 5.64<br>161 | 10.7 15.4<br>892 |
| 104P | 21.6 30.3<br>59 | 3.18 2.05<br>145 | | 3.61 6.15<br>248 | 3.45 6.35<br>259 | 6.78 9.82<br>64 | 5.12 11.1<br>801 |
| WEIGHTED MEANS | 11.1 19.6 | 3.09 4.73 | 7.19 9.34 | 5.14 8.28 | 3.54 5.45 | 3.54 7.09 | 6.50 13.6 |
| TOTAL SPLS | 5095 | 3457 | 3120 | 2524 | 584 | 3450 | 18798 |

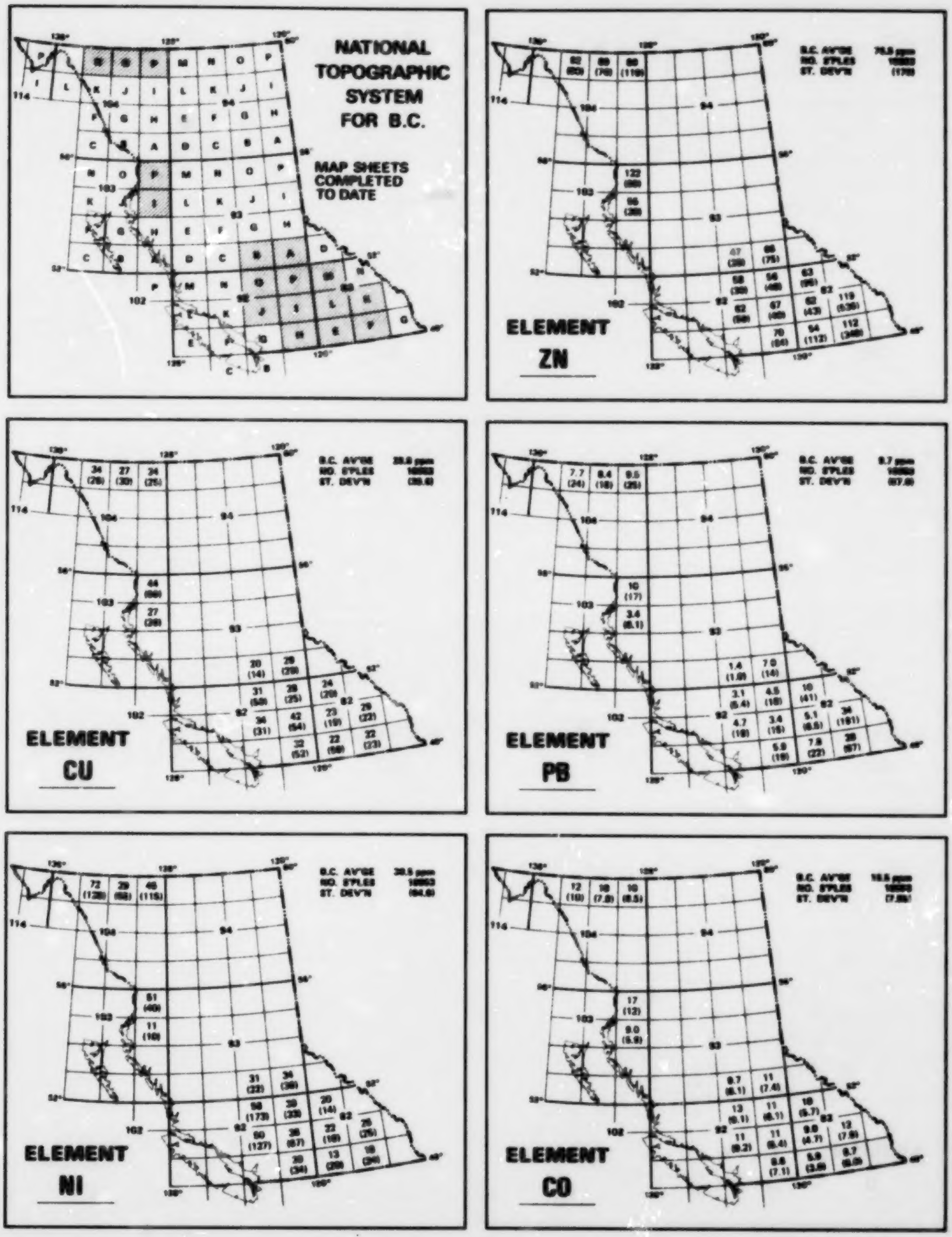

Figure 70. Map sheet averages for the 10 elements analysed for each rock type group (continued on page 200).

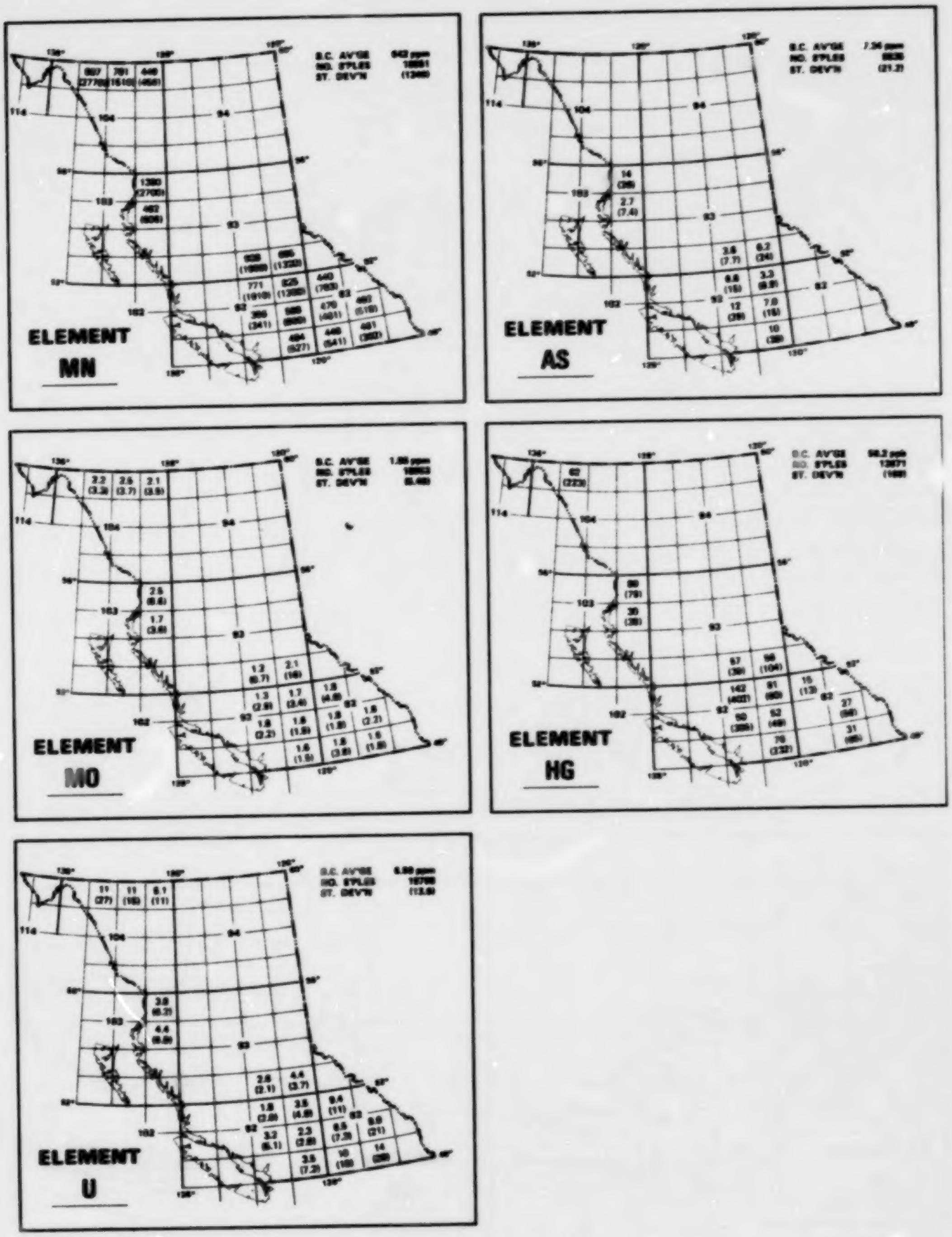

Figure 70 *(continued)*: Map sheet averages for the 10 elements analysed for each rock type group.

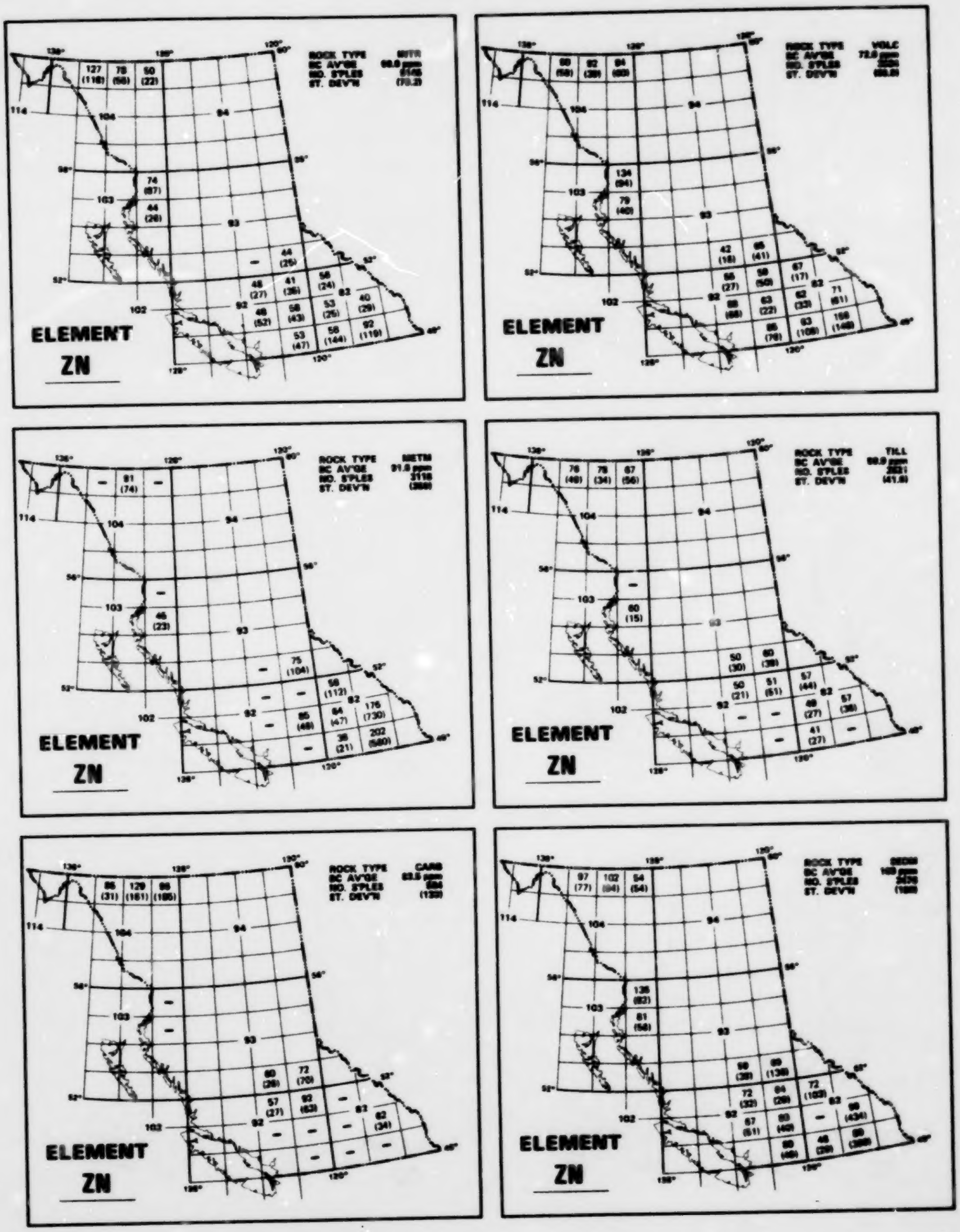

Figure 71. Map sheet average for zinc for each rock type group.

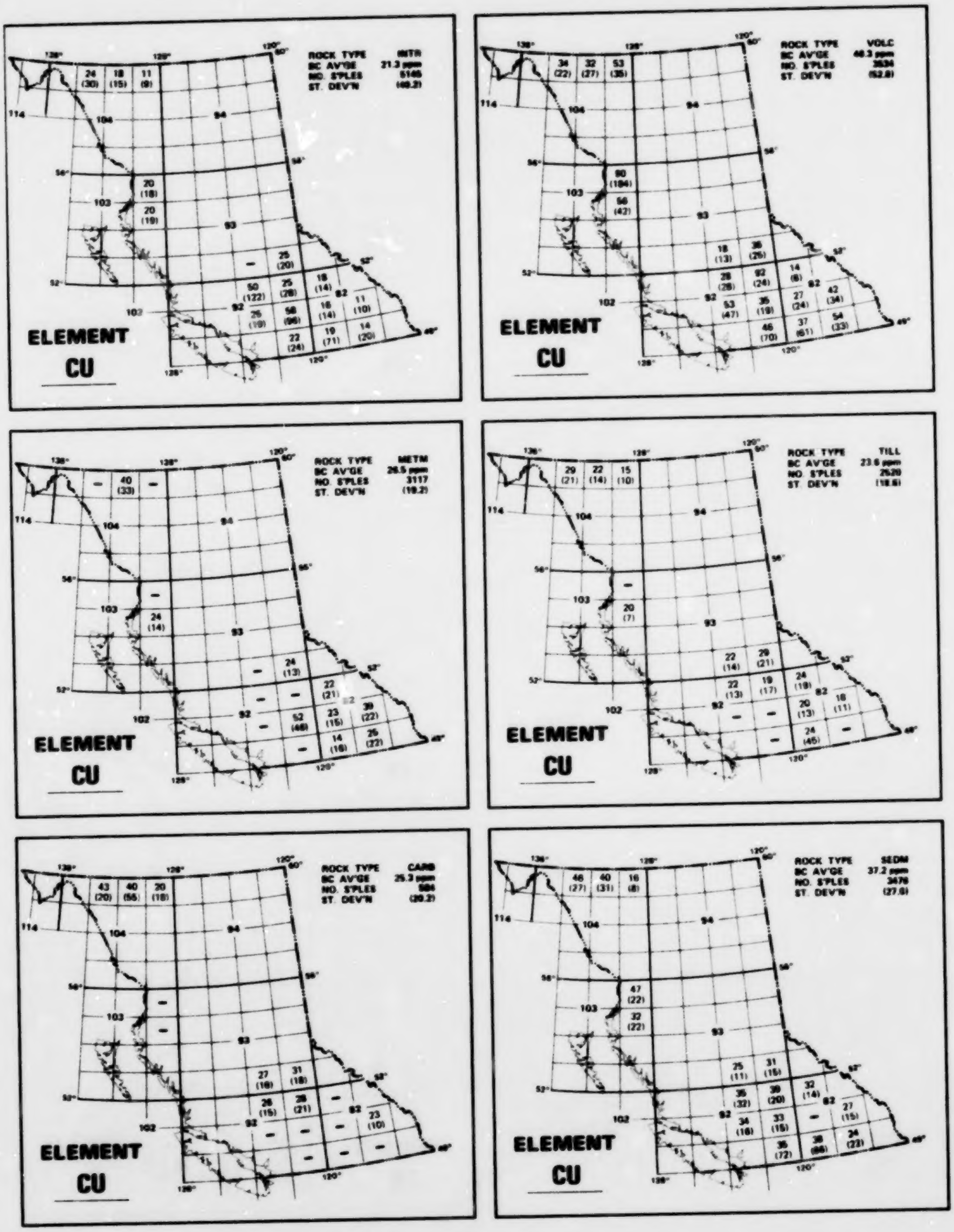

Figure 72. Map sheet average for copper for each rock type group.

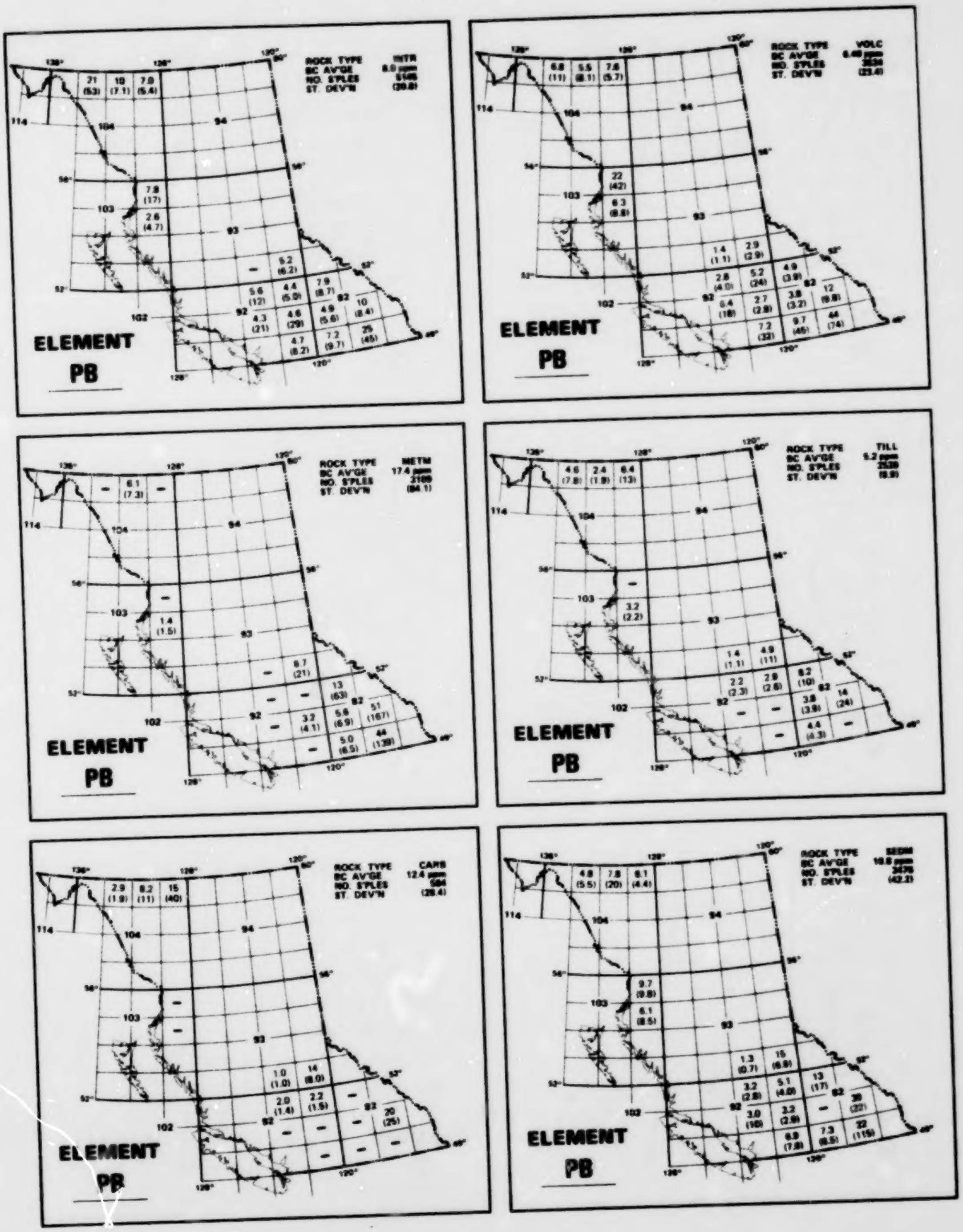

Figure 73. Map sheet average for lead for each rock type group.

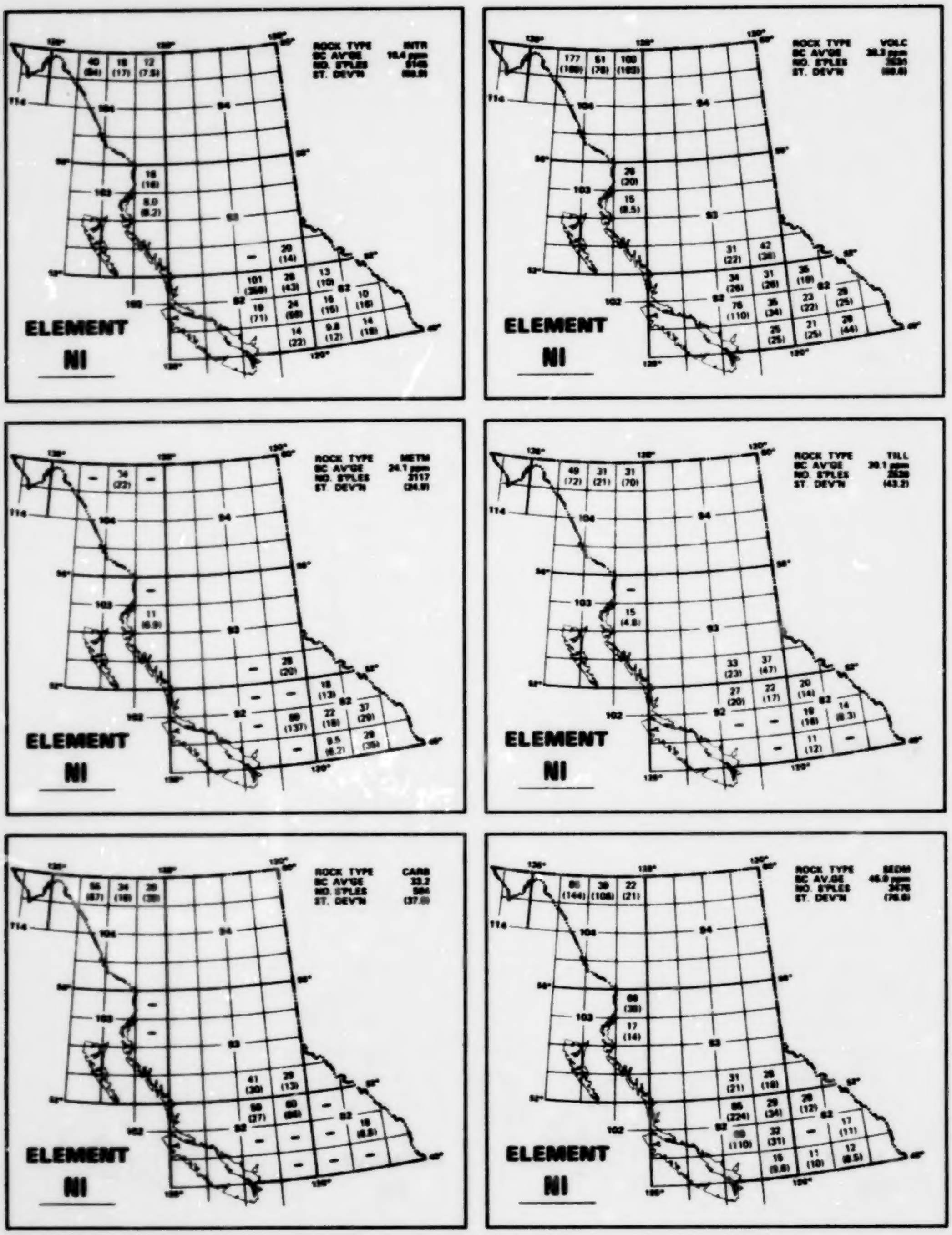

Figure 74. Map sheet average for nickel for each rock type group.

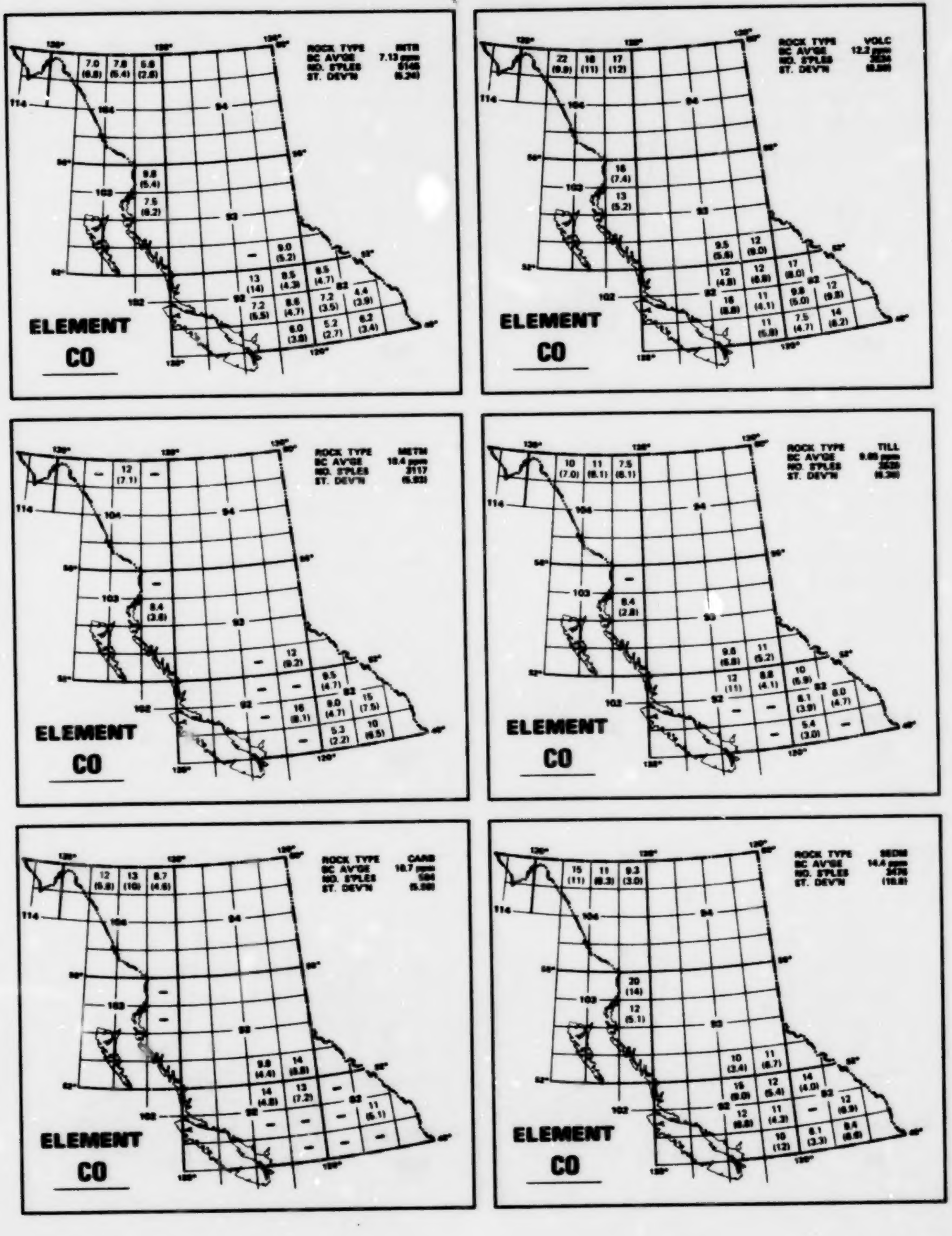

Figure 75. Map sheet average for cobalt for each rock type group.

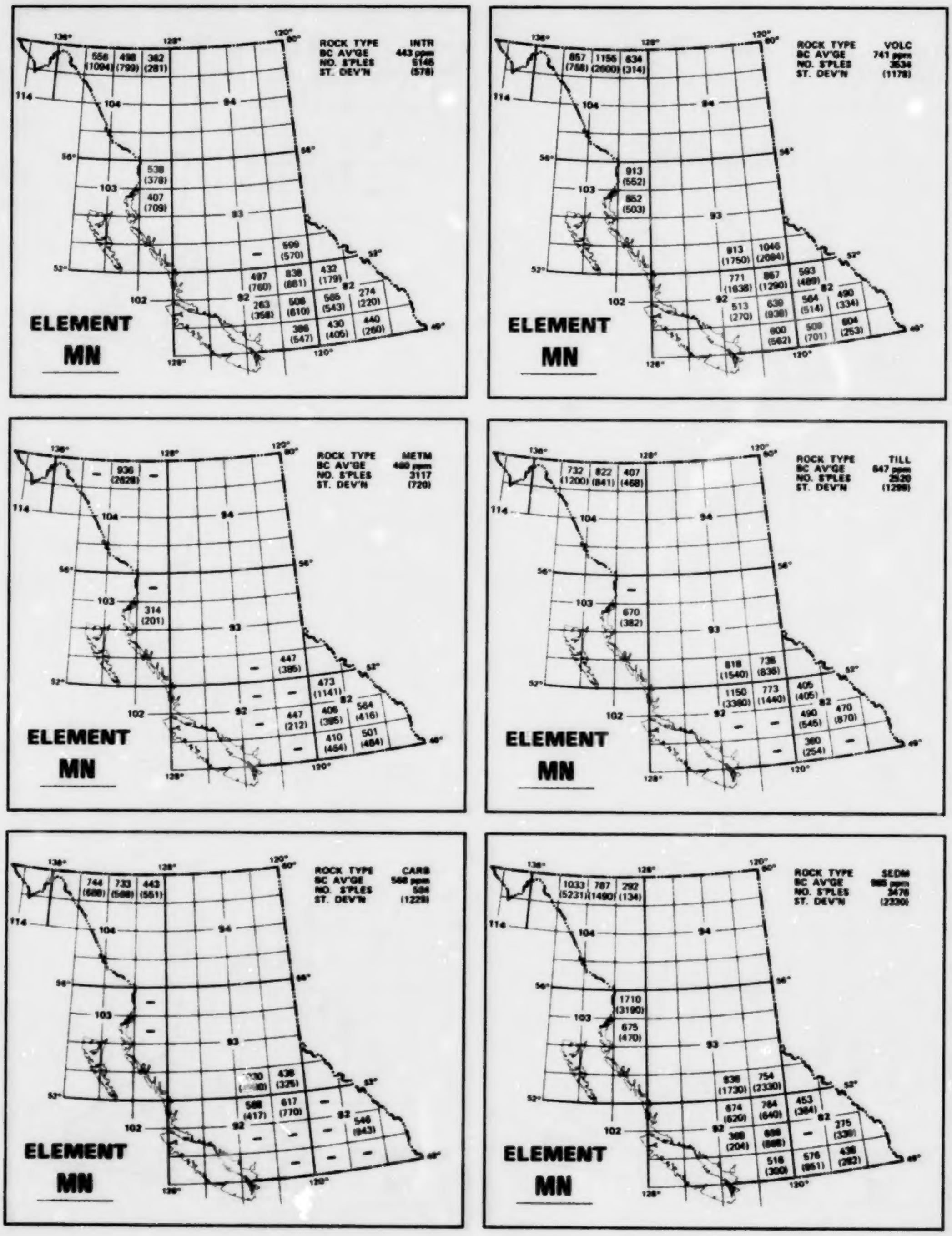

Figure 76. Map sheet average for manganese for each rock type group.

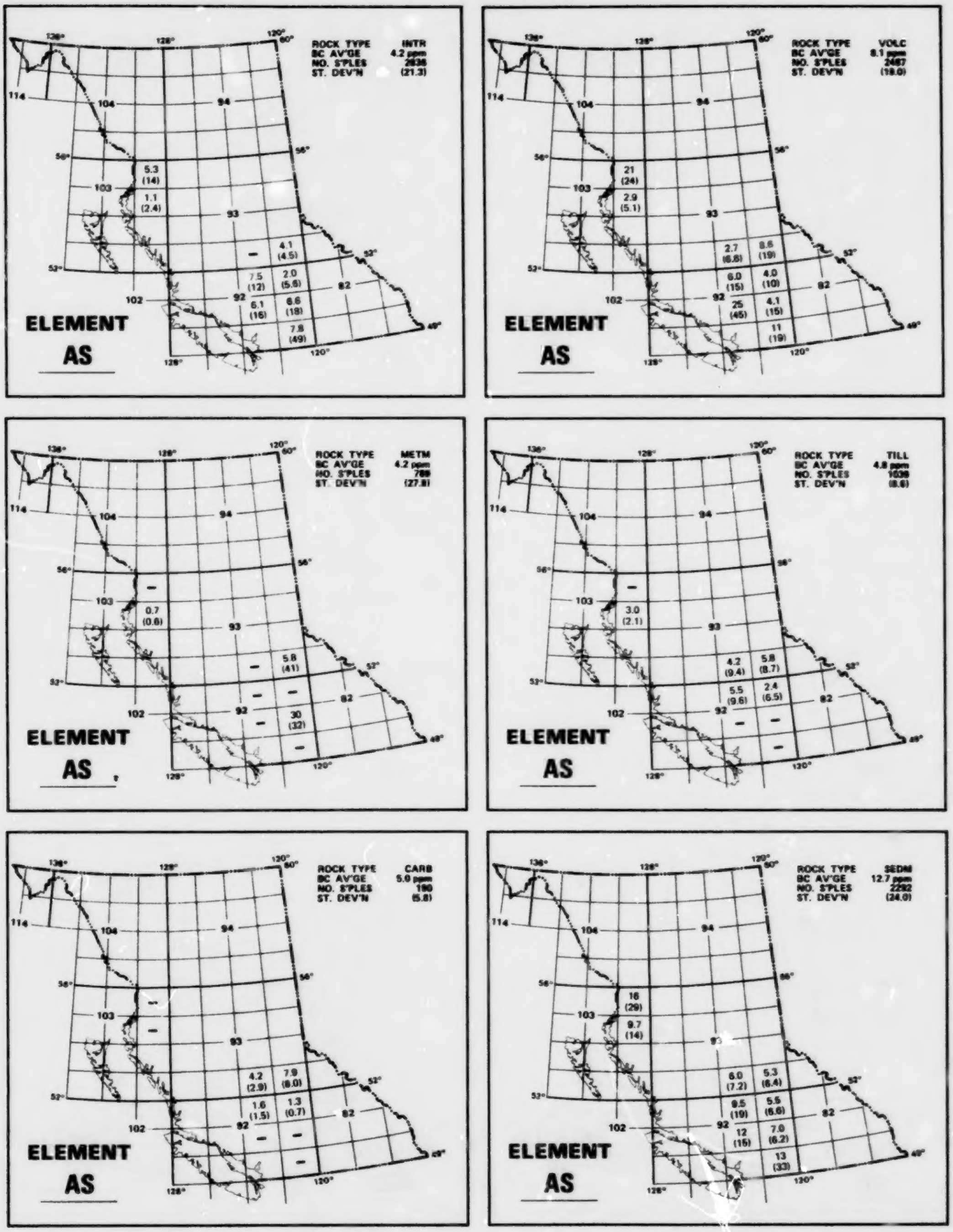

Figure 77. Map sheet average for arsenic for each rock type group.

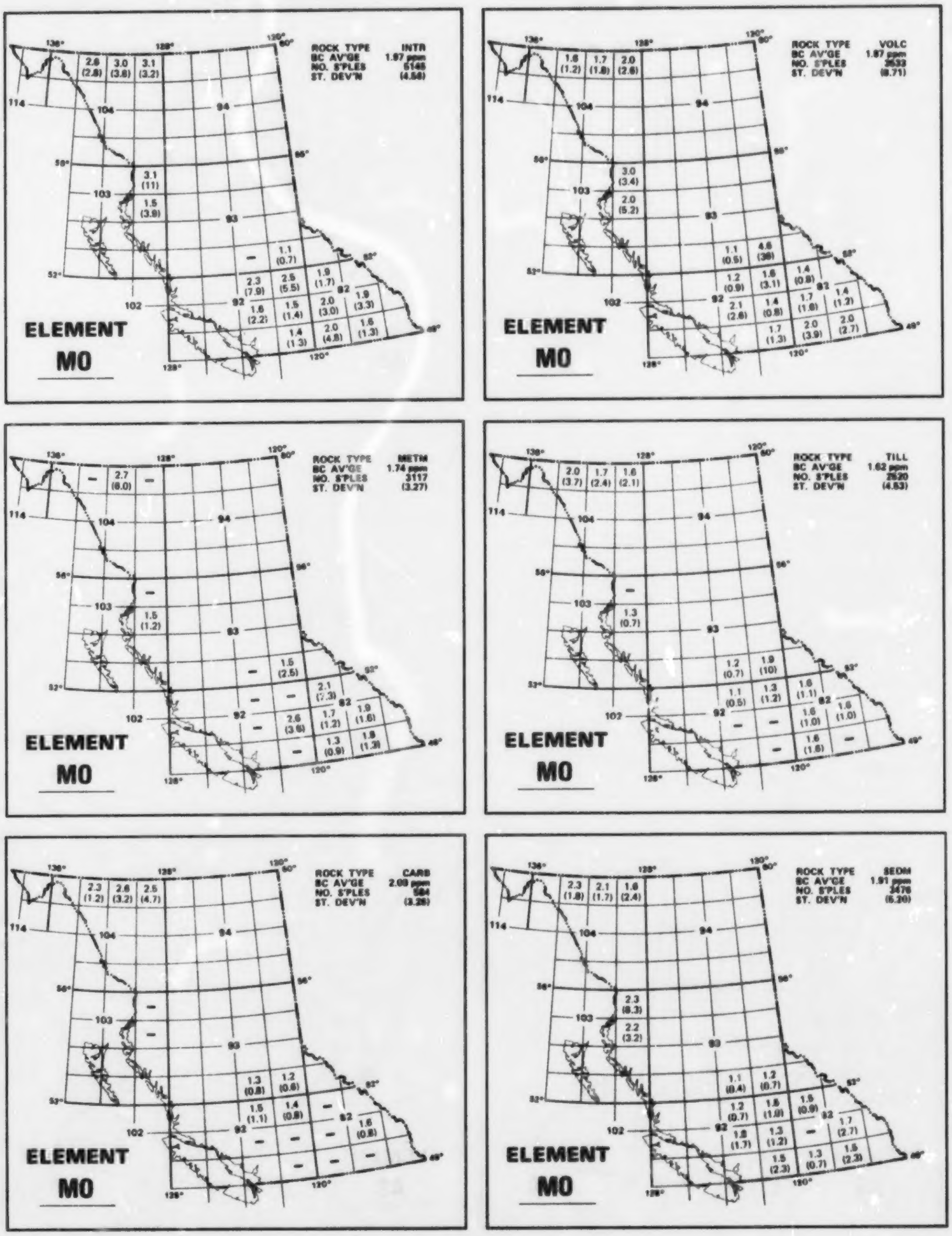

Figure 78. Map sheet average for molybdenum for each rock type group.

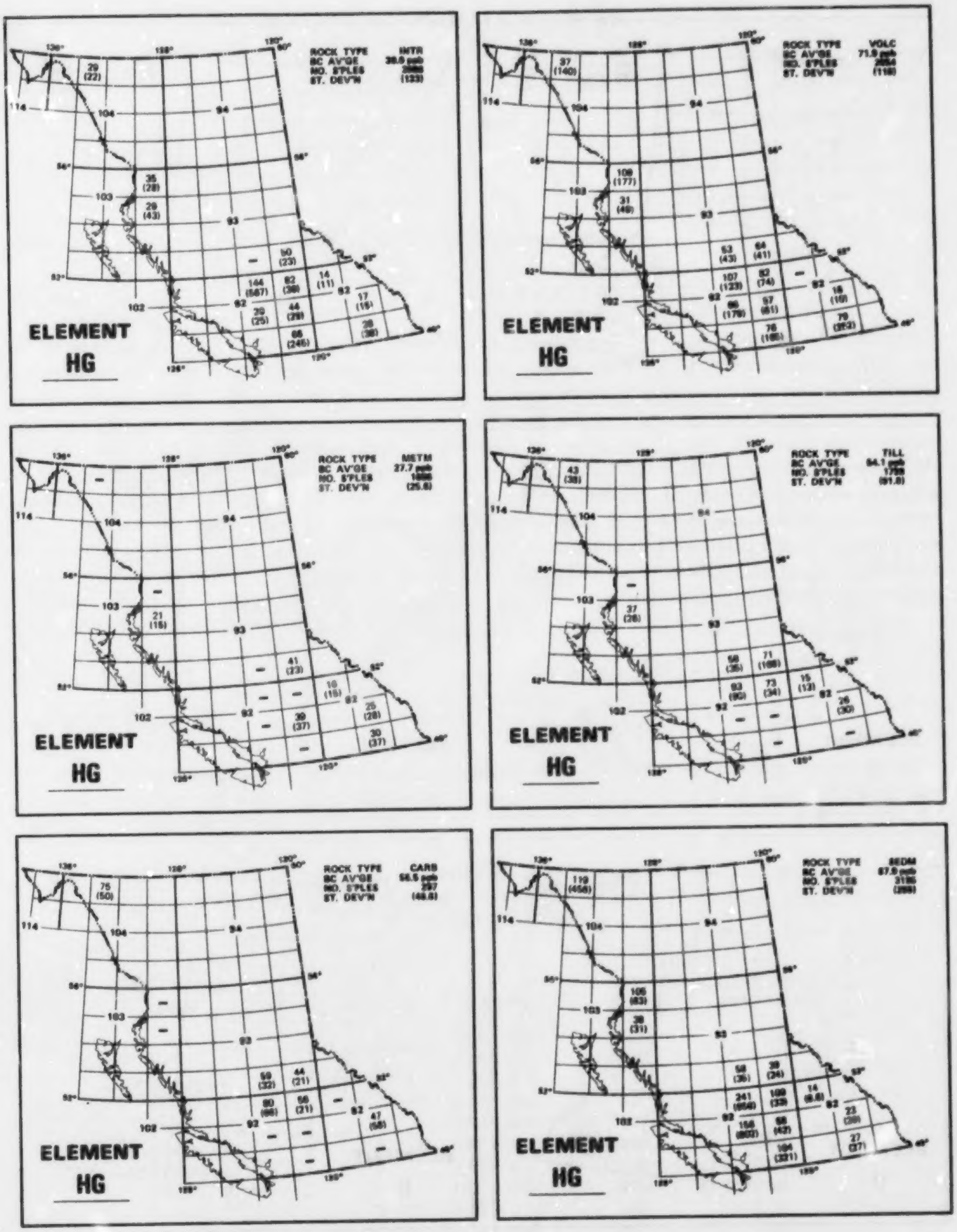

Figure 79. Map sheet average for mercury for each rock type group.

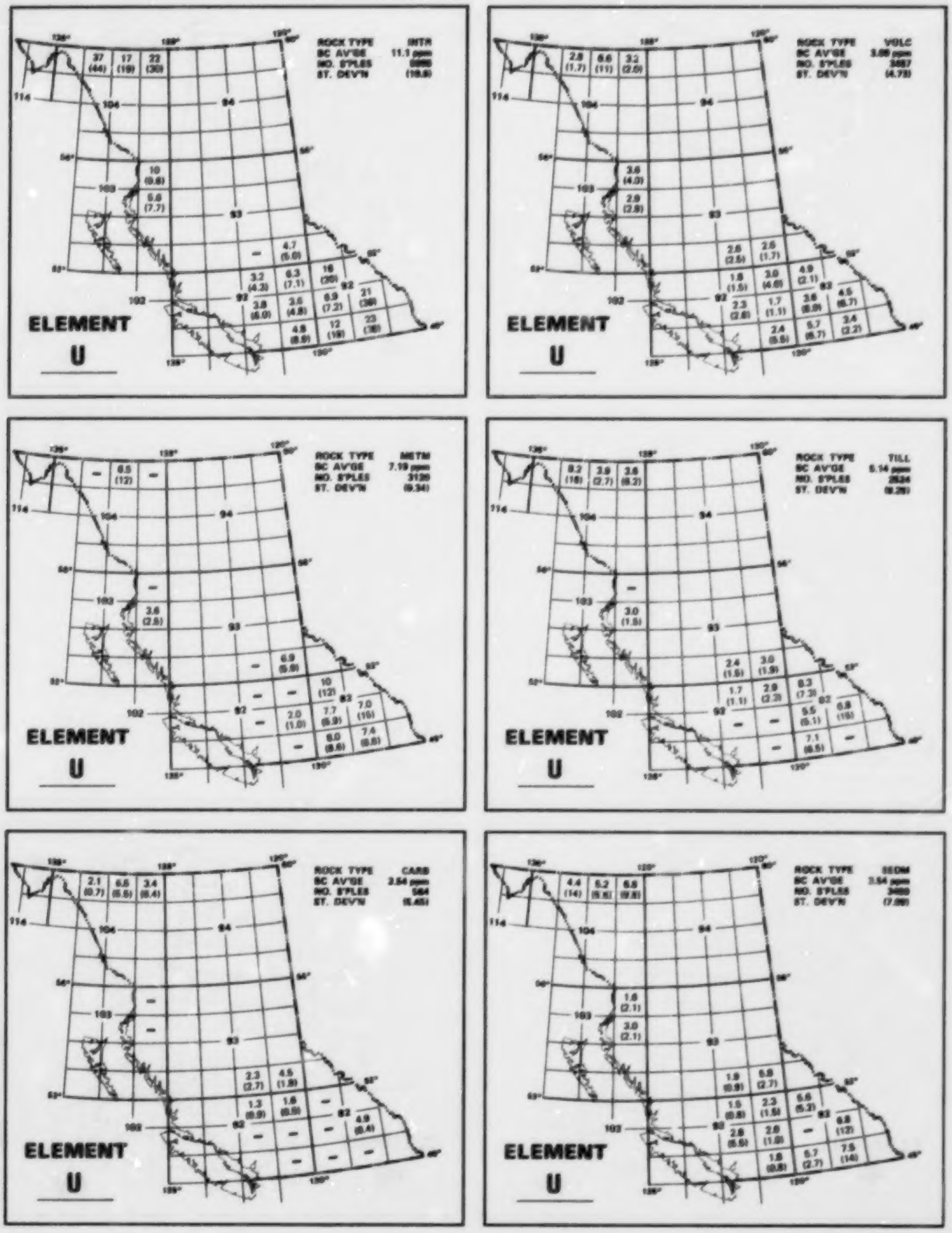

Figure 80. Map sheet average for uranium for each rock type group.

# INDUSTRIAL ZEOLITES AND RUTILE

By Z. D. Hora and Y.T.J. Kwong

## RUTILE (Titanium Minerals in Porphyry Copper/Molybdenum Tailings)

Recent studies on alternative sources and relevant occurrences of titanium minerals (for example, Force, 1976; Williams and Cesbron, 1977; Force, *et al.*, 1979) indicate that porphyry copper/molybdenum deposits could potentially supply a significant amount of byproduct titanium. Llewellyn and Sullivan (1980) investigated the feasibility of recovering rutile from mill tailings from the San Manuel copper deposit of Arizona; they contain 0.75 per cent titania. In view of these studies and as part of an industrial minerals assessment in British Columbia, a systematic examination of tailings from porphyry copper/molybdenum mines was initiated in 1982. Fourteen mines were chosen for the study. Cursory $TiO_2$ analyses are shown in the accompanying table. Most carry interesting amounts of titania; that is, employing an arbitrary cutoff grade of 0.50 per cent $TiO_2$; about half of these mines are of potential interest. Close examination of a high titania sample from the Ingerbelle orebody of Newmont Mines Limited revealed little variation in titania content in various size fractions; host minerals for titanium include ilmenite, sphene, magnetite, and mica. Similar detailed work is in progress for the other interesting deposits. If rutile, the most desirable titanium mineral for industrial purposes, is identified as a major titanium-containing species in a deposit, a feasibility test of mineral recovery will also be attempted.

## ACKNOWLEDGMENT

We thank the management of the mining companies listed in the accompanying table for supplying the majority of our test samples. R. Hibberson, P. Ralph, and V. Vilkos of the Analytical Laboratory contributed in the analysis of titania.

$TiO_2$ CONTENT OF TAILINGS
FROM SELECTED PORPHYRY COPPER/MOLYBDENUM DEPOSITS
IN BRITISH COLUMBIA

| NAME OF MINE | NO. OF SAMPLES | RANGE | PER CENT $TiO_2$ MEAN | STANDARD DEVIATION |
|---|---|---|---|---|
| Afton | 8 | 0.54 – 0.68 | 0.62 | 0.05 |
| Bell | 10 | 0.34 – 0.64 | 0.49 | 0.08 |
| Bethlehem | 2 | 0.35 – 0.43 | 0.39 | 0.06 |
| Boss Mountain | 6 | 0.14 – 0.34 | 0.23 | 0.07 |
| Brenda | 7 | 0.30 – 0.43 | 0.38 | 0.06 |
| Equity Silver | 4 | 0.81 – 0.97 | 0.84 | 0.08 |
| Gibraltar | 5 | 0.43 – 0.43 | 0.43 | 0.00 |
| Granby | 2 | 0.51 – 0.61 | 0.56 | 0.08 |
| Granisle | 8 | 0.40 – 0.78 | 0.56 | 0.13 |
| Highmont | 7 | 0.30 – 0.43 | 0.31 | 0.05 |
| Island Copper | 6 | 0.49 – 0.87 | 0.57 | 0.15 |
| Kitsault | 4 | 0.49 – 0.57 | 0.56 | 0.04 |
| Lornex | 12 | 0.30 – 0.43 | 0.35 | 0.05 |
| Newmont | 9 | 0.33 – 0.97 | 0.67 | 0.21 |

## ZEOLITES

### PRINCETON AREA (49° 26' – 120° 33'; 92H/7)

A random sampling program for industrial zeolites in volcanic sedimentary rocks has been underway since 1980; this year produced the first reported British Columbia locations of substantial zeolite content in these rocks in the Allenby Formation of the Middle Eocene Princeton Group. Results of previous sampling of tuffaceous deposits from the Penticton area, the vicinity of Kamloops and near Burns Lake, have been negative. High zeolite content in the Allenby Formation occurs in pale grey to yellow to yellowish grey volcanic ash beds. Clinoptilolite (approximately 25 to 35 per cent) together with similar quantities of stilbite form the main component of this fine to coarse-grained devitrified ash. Three samples with high zeolite content are part of the sequence of volcanic sandstones and tuffs exposed in a road cut on Highway 3 approximately 5 kilometres southwest of Princeton.

## REFERENCES

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Force, E. R., Czamanske, G. K., and Moore, W. J. (1979): Rutile from Porphyry Copper Deposits: Technical Program, *Society of Mining Engineers*, Feb. 1980, Las Vegas, p. 21.

Llewellyn, T. O. and Sullivan, G. V. (1980): Recovery of Rutile from Porphyry Copper Tailings, *U.S. Bureau of Mines*, Report of Investigations 8462, 18 pp.

Williams, S. A. and Cesbron, F. P. (1977): Rutile and Apatite: Useful Prospecting Guides for Porphyry Copper Deposits, *Mineralogical Magazine*, Vol. 41, pp. 288-292.

# INDUSTRIAL MINERALS AND STRUCTURAL MATERIALS

By Z. D. Hora

The 1983 field work consisted of property visits and examinations throughout the Province. The following descriptive report highlights magnesite, barite, limestone, and building stone prospects.

## MAGNESITE

### DRIFTWOOD CREEK AREA (50° 54' – 116° 34'; 82K/15)

This new occurrence is in the Upper Purcell Mount Nelson Formation of Proterozoic age (Fig. 81). Medium to coarse-grained crystalline magnesite of white to yellowish white and pale grey colours forms steep

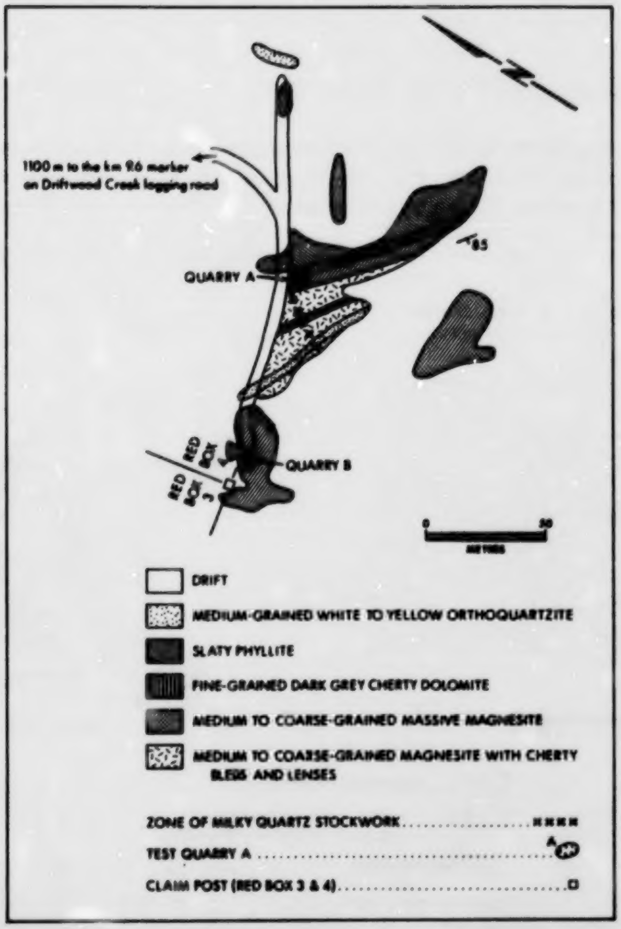

N
1100 m to the km 9.6 marker
on Driftwood Creek logging road
85
QUARRY A
QUARRY B
RED BOX 4
RED BOX 3
0
30
METRES
DRIFT
MEDIUM-GRAINED WHITE TO YELLOW ORTHOQUARTZITE
SLATY PHYLLITE
FINE-GRAINED DARK GREY CHERTY DOLOMITE
MEDIUM TO COARSE-GRAINED MASSIVE MAGNESITE
MEDIUM TO COARSE-GRAINED MAGNESITE WITH CHERTY BLEBS AND LENSES
ZONE OF MILKY QUARTZ STOCKWORK
TEST QUARRY A
A
CLAIM POST (RED BOX 3 & 4)

Figure 81. Driftwood Creek magnesite, 82K/15.

southwesterly dipping beds (85 degrees) in a zone approximately 110 metres wide. While the upper main 45 metres of exposed magnesite is a massive rock with no visible impurities, the lower 65 metres contains cherty lenses and blebs of variable proportions, reaching up to 50 per cent of the rock. Within the lower zone there are two continuous massive magnesite beds 2.2 metres and 4.5 metres thick. In June 1983, a sample for metallurgical testing was taken at this site from two newly opened test quarries.

The main massive magnesite bed (upper zone) extends along strike for at last several hundreds of metres; it may continue for more than 1 kilometre.

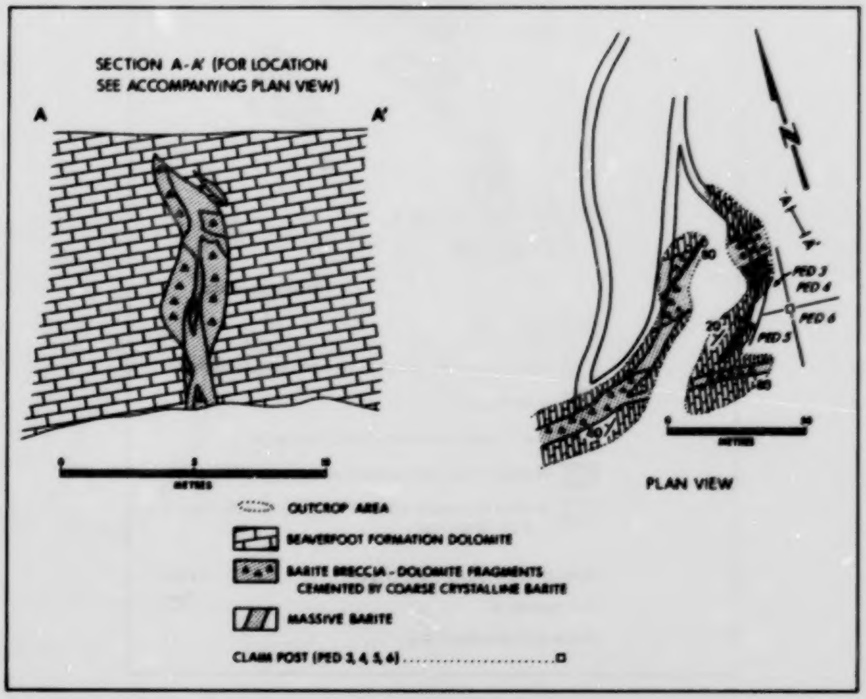
|  | MgO<br>*Per Cent* | CaO<br>*Per Cent* | $SiO_2$<br>*Per Cent* | $Al_2O_3$<br>*Per Cent* | $Fe_2O_3$<br>*Per Cent* |
|---|---|---|---|---|---|
| Test Quarry A | 42.5 | 4.20 | 2.5 | 0.06 | 0.77 |
| Test Quarry B | 40.0 | 6.00 | 4.6 | 0.13 | 0.82 |

The showing is on the northwestern end of the rocky ridge on the northern side of Driftwood Creek. The test pit site can be reached by Driftwood Creek logging road and is 9.6 kilometres northwest from the Bugaboo road intersection.

## BARITE

### PEDLEY MOUNTAIN (50° 25′ – 115° 43′; 82J/5)

Barite is exposed on steep north-facing slopes 3 kilometres northeast of Mount Pedley at an elevation of approximately 1 800 metres (Fig. 82). The showing consists of brecciated barite in a vein with many irregular offshoots and branches; it has a general strike of 30 degrees and dips 80 degrees southeast. The


SECTION A-A′ (FOR LOCATION
SEE ACCOMPANYING PLAN VIEW)
A
A′
0
5
10
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PED 3
PED 4
PED 6
PED 5
80
20
80
0
METRES
PLAN VIEW
OUTCROP AREA
BEAVERFOOT FORMATION DOLOMITE
BARITE BRECCIA - DOLOMITE FRAGMENTS
CEMENTED BY COARSE CRYSTALLINE BARITE
MASSIVE BARITE
CLAIM POST (PED 3, 4, 5, 6) ........................□

Figure 82. Pedley Mountain barite, 82J/15.

barite is exposed in two areas separated by a vertical distance of approximately 100 metres. The barite is white in colour and coarse grained; galena in scattered grains and aggregates is a common accessory component. The surrounding rocks are massive, brittle dolomites of the Upper Ordovician/Lower Silurian Beaverfoot Formation. The dolomites, which are greyish brown in colour at this site, strike east-west and dip 20 degrees to 40 degrees to the north. In 1982-83, Bar-Well Resources Ltd. of Calgary mined several thousand tonnes of Pedley Mountain barite ore; it was processed in the Windermere plant. The mining road to the site starts at a point on the Old Settlers road, 8 kilometres north of the Palliser River logging road and 1 kilometre south of the Pedley Creek bridge.

### WINDERMERE (50° 26' – 115° 53'; 82J/5)

Irregular patches of barite from the west-sloping sidehill 8 kilometres southeast of Windermere were originally described in 1970 by J. W. McCammon. Mining on this property from 1981 to 1983 produced more than 10 thousand tonnes of baritic ore.

The original showing consisted of barite lenses and offshoots developed within and near a mylonitic shear zone that strikes east-west (105 degrees) and dips 20 degrees south. In addition to the main showing, sporadic pods, short veins, and breccia zones of barite were exposed in an area approximately 500 metres to the southeast (Fig. 83). The barite occurs in massive, fine-grained, light grey Upper Jubilee dolomite; there is an almost complete absence of recognizable bedding. Barite in all these showings is coarse grained and milky white with occasional grains of galena and less common copper stains. The location and access were described by McCammon (1971).

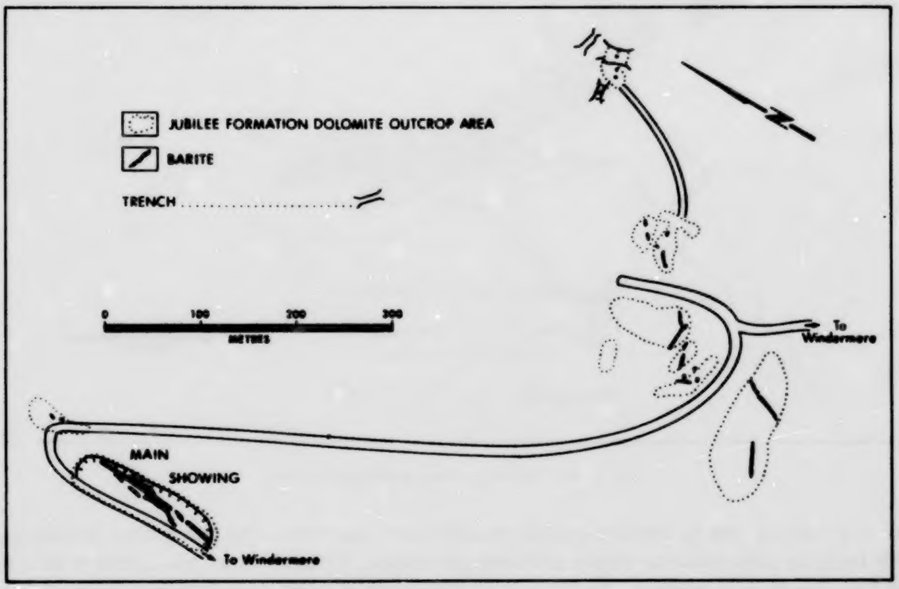

Figure 83. Windermere barite, 82J/15.

## LIMESTONE

### BOWRON RIVER (53° 42' – 121° 42'; 93H/12)

In 1983 a banded grey marble of the Lower Cambrian Mural Formation was developed into a small quarry by Western Lime and Marble Inc. of Prince George. The quarry is located on the eastern side of Bowron

River, 27 kilometres south of Highway 16, and can be reached by both Giscome and Bowron logging roads. The rock is medium grained and massive; it is processed on the site into agriculture grade limestone. A random sample of the crushed rock provided the following analysis:

| CaO<br>*Per Cent* | MgO<br>*Per Cent* | $SiO_2$<br>*Per Cent* | $Al_2O_3$<br>*Per Cent* | $Fe_2O_3$<br>*Per Cent* |
|---|---|---|---|---|
| 46.8 | 7.60 | 0.34 | 0.08 | 0.11 |

## BUILDING STONE

### McGREGOR PASS (53° 58′ – 120° 14′; 93H/16)

Massive beds of beige-coloured orthoquartzite of the Lower Cambrian Mahto Formation are quarried in large blocks for building-stone applications. The quarry site is located on the continental divide at an elevation of 1 700 metres north of Wishaw Lake (Fig. 84).

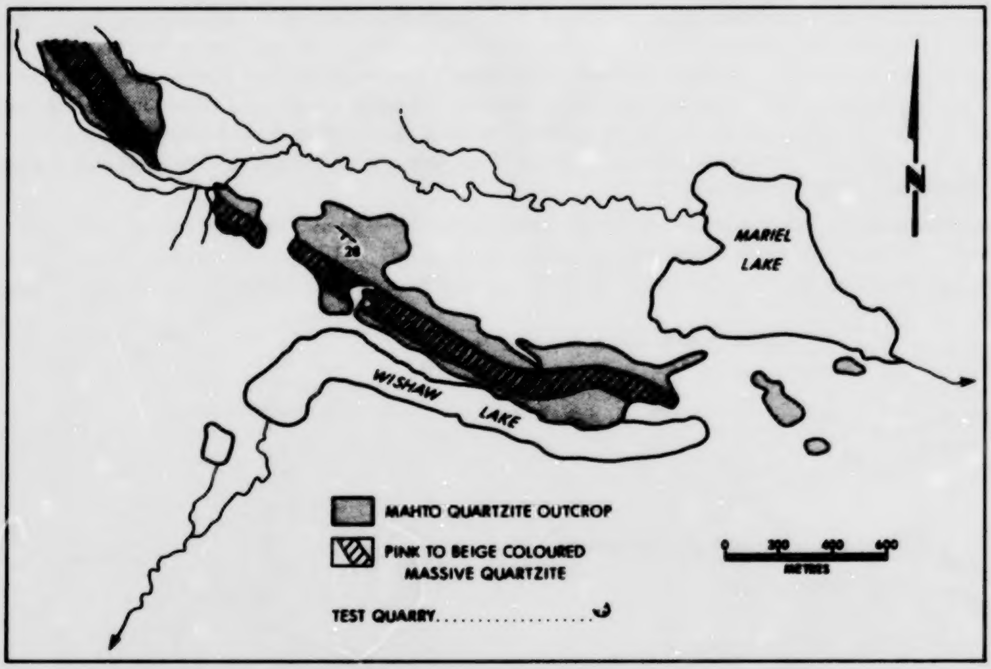

Figure 84. McGregor Pass quartzite, 93H/6.

The rock is a massive, fine to medium-grained, cross-bedded quartzite. The test quarry opened quartzite beds with beige to pink-coloured stripes and irregular smears. In appearance, the quartzite can compete with the best commercial marbles. In the quarry, the quartzite splits along bedding planes of 1.0 metre to 2.0 metres apart; in several cases the separating bedding plane has a very uneven deeply dotted surface like wet sand after a hailstorm. The beds strike uniformly at 70 degrees and dip 28 degrees south. About one third of the exposed 300-metre to 350-metre width of Mahto quartzite at Wishaw Lake constitutes the commercially interesting beige and pink-coloured rock.

The physical properties of this brittle, but very strong and competent rock are comparable to the best varieties of granite on the building-stone market, but it is more difficult to achieve the same closed and evenly distributed high lustre by polishing.

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# OTHER INVESTIGATIONS

## A PRELIMINARY ASSESSMENT OF ZEBALLOS MINING CAMP
## (92L)

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A MINDEP PROJECT
Department of Geological Sciences, University of British Columbia

### INTRODUCTION

This report updates and expands a preliminary report published last year on assessing resource potential of gold quartz veins in the Zeballos camp (Sinclair and Hansen, 1983). The Zeballos camp is located on the west coast of Vancouver Island (Fig. 85).

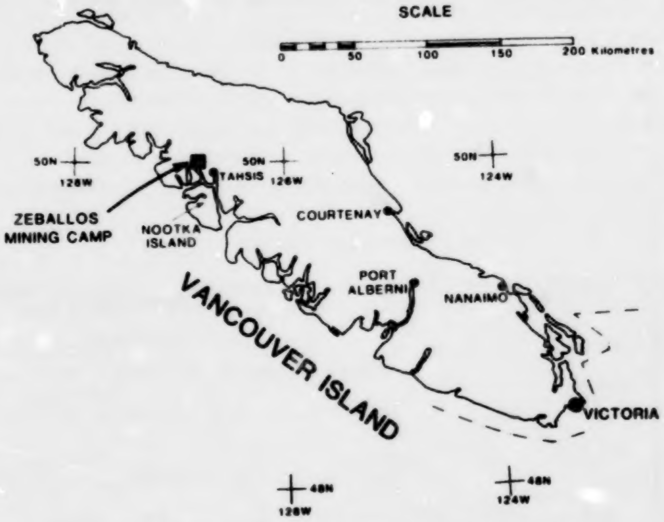

Figure 85. Location map of the Zeballos mining camp.

This evaluation was initially oriented toward a quantitative resource assessment following the approach of Sinclair (1979) and Orr and Sinclair (1971). To this end a data file was constructed (*see* Sinclair and Hansen, 1983, Table 1) to form a basis for quantitative evaluation.

Because of the scarcity of quantitative data the study was broadened to include a qualitative assessment of geological features, particularly structure. This was hampered to a certain extent by a lack of field observations.

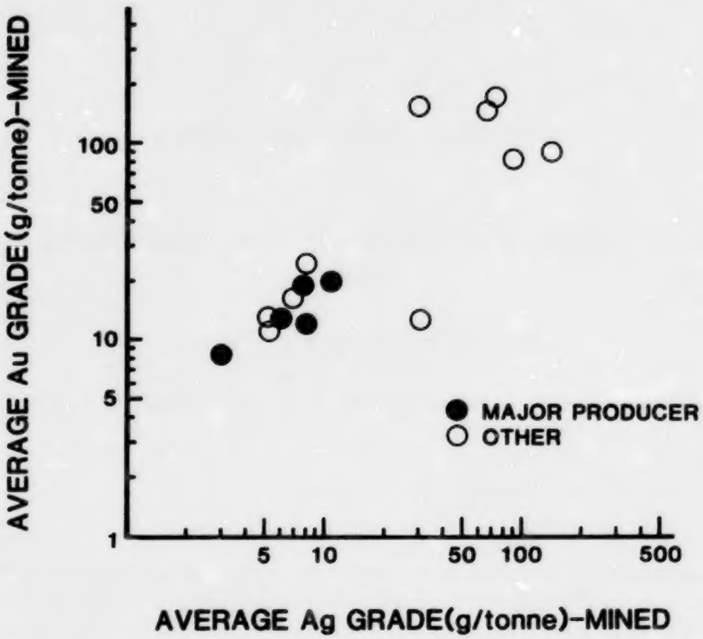

Figure 86. Plot of average gold grades (grams per tonne) versus average silver grades (grams per tonne) for Zeballos vein deposits.

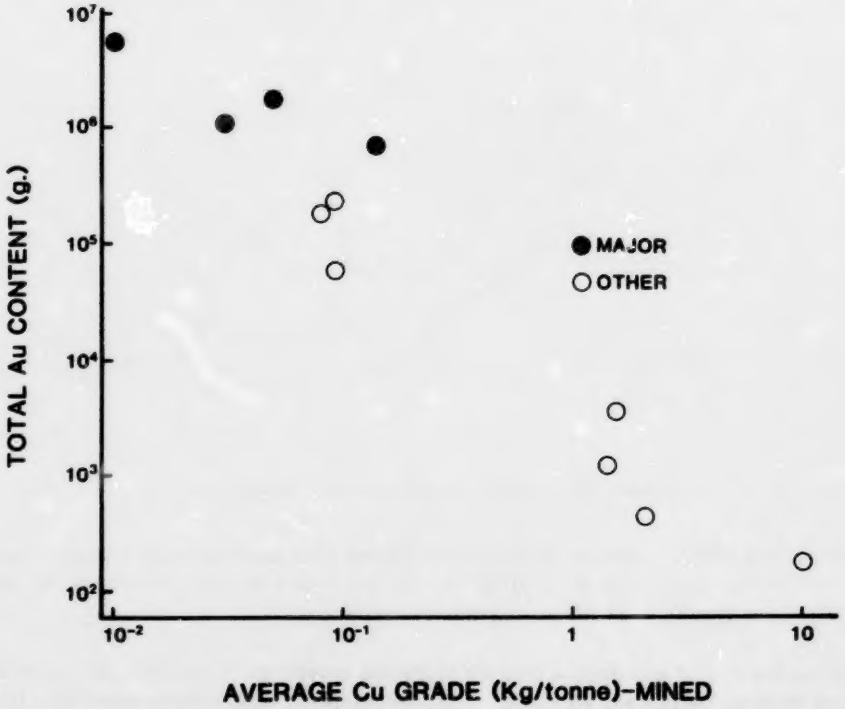

Figure 87. Total gold content (grams) versus average copper grades (percentage) for Zeballos vein deposits.

## DATA BASE

The data have been compiled (Sinclair and Hansen, 1983) from two primary sources of information: a report and map by Stevenson (1950) and the MINFILE computer file of mineral deposits in British Columbia maintained by the British Columbia Ministry of Energy, Mines and Petroleum Resources. These tables are reproduced in updated form in an appendix. For comments on the terminology used, please refer to Sinclair and Hansen (1983).

## STATISTICAL METHODS AND RESULTS

The following techniques all utilize the data as listed in Tables 1 to 5 in Sinclair and Hansen (1983). The small number of observations for which production data are available is a significant drawback which limits the potential of using multivariate techniques. Nonetheless, there are some interesting relationships and trends apparent, as described following. Those variables which do not display an approximately normal distribution, for example, all production data, are log normal and were invariably log transformed. No other transformations were considered necessary.

## LINEAR REGRESSION

Selected plots of the more significant relationships are discussed, with the associated statistical values listed in Table 1. Precious metal contents (gold and silver) when plotted versus production (Sinclair and Hansen, 1983) showed good correlation between 'mined tonnage' and both gold and silver content, therefore production tonnage is an acceptable single measure of relative value of vein deposits of the Zeballos camp (compare, Sinclair, 1979). The corollary is that average grades among the larger producers are relatively constant. This would be of significant interest to any future producer at the camp. Average gold grade versus average silver grade is shown on Figure 86. Although the correlation is high (r = 0.815), the existence of two clusters suggests that this may be at least partly artificial. Nonetheless the cluster representing the larger producers is valid. It can be seen that gold grade is considerably higher than that of silver, the mean ratio is 2:3, with a standard deviation of 1:3; for the larger producers these values are 2:3 and 0:5 respectively.

TABLE 1. LINEAR REGRESSION DATA

| DEPENDENT VARIABLE | INDEPENDENT VARIABLE | NUMBER OF OBSERVATIONS | DEGREE OF FREEDOM | CORRELATION COEFFICIENT | RELEVANT FIGURE |
|---|---|---|---|---|---|
| LogMINE | LogTOAU | 17 | 16 | 0.989 | 2.1 |
| REGRESSION EQUATION LogMINE = 1.23·LogTOAU – 2.46 | | | | | |
| LogMINE | LogTOAG | 15 | 14 | 0.975 | 2.1 |
| REGRESSION EQUATION LogTOAG = 1.18·LogTOAG – 1.94 | | | | | |
| LogGRAU | LogGRAG | 15 | 14 | 0.815 | 2.2 |
| REGRESSION EQUATION LogGRAU = 0.75·LogGRAG = 0.59 | | | | | |
| LogTOAU | LogGRCU | 11 | 10 | –0.962 | 2.3 |
| REGRESSION EQUATION LogTOAU = –1.62·LogGRCU + 3.61 | | | | | |
| LogTOAU | DSTC(+ve) | 8 | 7 | –0.637 | 2.4 |
| REGRESSION EQUATION LogTOAU = –0.0019·DSTC + 6.38 (within stock) | | | | | |
| LogTOAU | DSTV(–ve) | 9 | 8 | 0.713 | 2.4 |
| REGRESSION EQUATION LogTOAU = 0.0011·DSTC + 5.38 (in wallrock) | | | | | |

ABBREVIATIONS:

MINE = mined tonnage per deposit (tonne)

TOAU, TOAG = total grams gold per deposit, total grams silver per deposit

GRAU, GRAG, GRCU = grade of gold in grams per tonne, grade of silver in grams per tonne, grade of copper in kilograms per tonne

DSTC = distance from the Zeballos stock contact

On Figure 87, total grams of gold per deposit are plotted against average grade of copper. The good negative correlation over several orders of magnitude suggests copper grade may be an indicator of deposit relative value. However, this correlation may be partly artificial, as a result of selective up-grading of ore in the small deposits. This relationship is discussed further in the following section on multiple regression.

When a plot of deposit relative value (total grams of gold per deposit) was made against distance from the contact of the Zeballos stock (Sinclair and Hansen, 1983; Fig. 106), the graph showed a remarkably consistent pattern both in the stock and in the country rock. The equations describing these trends are given in Table 1. There is potential for this relationship to be used as a value estimate for any deposits remaining to be discovered. However, two assumptions are implicit in this relationship. First, the measure of distance from the contact is in the horizontal plane, potential influence of variation in the vertical plane is not considered. Second, the Zeballos stock is considered to be the only Tertiary intrusive in the vicinity; this may not be true.

## MULTIPLE REGRESSION

The method used is called backward stepwise regression; in it, only the most significant variable(s) are retained in the equation at the final step. Although the potential of this method is severely limited by the small number of observations available, it has provided insight into which variables may reflect the mineralizing process.

Numerous runs were made using different dependent variables and combinations of all or some independent variables; in addition the numbers of observations used were varied.

Naturally the most significant dependent variables as value indicators are mined tonnage and total gold content per deposit. Elevation was used as a dependent variable in an attempt to define any zoning which may be present. The data are too sparse to allow any meaningful correlations.

The use of mined tonnage or total gold content as dependent variables restricts the number of observations to 18 and 17 respectively. If complete observations are desired the restrictions are even more severe, generally less than 10 or so observations. Where observations are incomplete, mean values are substituted for missing data. The results often do not appear significantly different in such cases.

The most significant independent variables, in approximate order of decreasing significance, are: grade of copper (GRCU), grade of gold (GRAU), bearing from the northwest nose of the Zeballos stock to the deposit (BRGN), distance to the contact (DSTC), average minimum vein width (MNVW), grade of silver (GRAG), grade of lead (GRPB), distance to the nose of the stock (DSTN), strike of the major vein(s) (STR1). This order varies depending on the nature of the other parameters. Of the nine variables only six are considered to be of geological significance. The variables DSTN and STR1 were dropped primarily because of their low rating in various statistical runs. In addition, the values for STR1 are averages and would be difficult to determine for a raw prospect.

The variable MNVW, although useful, was dropped for two reasons: it is an empirically determined value, and it is of no quantitative value when considering a prospect with limited vein exposure. The variables GRAG and GRPB were retained because they are quantitative production data and represent information which is relatively easy to obtain from a prospect. The variable BRGN was retained solely because of its significance in the regression analyses. It is difficult to explain geologically except insofar as it is presumably an indirect measure of other variables of significance, as discussed elsewhere (for example, position and orientation of shears).

Data resulting from the use of these six variables are presented in Table 2. The cases presented demonstrate the type of results obtained. Features of interest are: the high values for $R^2$ (that is, that fraction of total variance explained by the relationship), the generally low standard error (around a half order of magnitude over five to seven orders of magnitude), and the persistence of GRCU as the retained independent variable. It appears that the grade of copper is of considerable, unexpected significance in terms of available data. This supports the conclusion in the previous section that grade of copper may well be useful as an indicator of potential value of a deposit.

TABLE 2. SELECTED RESULTS FROM MULTIPLE REGRESSION ANALYSES

| DEPENDENT VARIABLE | MINE | TOAU | MINE | TOAU |
|---|---|---|---|---|
| INDEPENDENT VARIABLE | GRAU, GRAG, GRCU, GRPB | GRAU, GRAG, GRCU, GRPB | GRAU, GRCU, DSTC, BRGN | GRAU, GRCU, DSTC, BRGN |
| TOTAL NO. OF OBSERVATIONS | 18 | 17 | 12 | 12 |
| TOTAL NO. OF COMPLETE OBSERVATIONS | 9 | 9 | 11 | 11 |
| DEGREES OF FREEDOM | 11 | 11 | 11 | 11 |
| FINAL STEP NUMBER | 8 | 7 | 7 | 7 |
| LAST VARIABLE REMOVED | GRAU | GRAG | BRGN | BRGN |
| RETAINED VARIABLE(S) | GRAG, GRCU | GRCU | GRAU, GRCU | GRCU |
| VALUE OF $R^2$ | 0.97 | 0.93 | 0.97 | 0.93 |
| STANDARD ERROR | 0.41 | 0.50 | 0.40 | 0.48 |
| REGRESSION EQUATION | LogMINE = −0.97·LogGRAG<br>−1.67·LogGRCU<br>+3.09 | LogTOAU = −1.62·LogGRCU<br>+3.09 | LogMINE = −1.25·LogGRAU<br>−1.53·LogGRCU<br>+3.97 | LogTOAU = −1.62·LogGRCU<br>+3.60 |

NOTES: Abbreviations explained in text; all values are logged (as shown), except DSTC and BRGN.

## CLUSTER ANALYSIS

Much of the data file consists of attributes, that is to say, measurements recorded on a nominal scale and having discrete values. Although such data may be evaluated empirically, it was considered that more significant results might be derived using a parametric statistical technique. It was desired to group the data from Associated Minerals using cluster analysis, after ensuring that it was valid to use such data in such a manner. The lower orders of clustering were meaningful, but did not provide information that could not be determined empirically. The higher orders of clustering did not appear to be geologically significant. It was presumed, therefore, that there is no practical grouping of observations within these data, other than what can be determined empirically.

## GEOLOGY AND MINERALIZATION

### GENERAL

The geology of Zeballos camp, as shown on Figure 88, consists of a northwest-striking, southwest-dipping sequence of Mesozoic volcanic and sedimentary rocks cut by Jurassic and Tertiary intrusions. The general structure represents the southwestern limb of a northwesterly trending anticline (Hoadley, 1953), considerably disrupted by faults and intrusions. The area to the north of the Zeballos stock and to the east of the North Fork of the Zeballos River is tightly folded. The Lower Jurassic Bonanza Group is a typical island arc sequence, largely consisting of basaltic to rhyolitic volcanic rocks. This unit is underlain conformably by limestone of the Quatsino Formation. These two units are now thought to be separated by the Parson Bay Formation as elsewhere on Vancouver Island; this is described in detail following. Tholeiitic basalts of the Upper Triassic Karmutsen Formation form the base of the sequence in this area. These bedded rocks are cut by Jurassic plutons of the Island Intrusions, mainly diorite to granodiorite in composition. The Zeballos stock with its spatially related gold-quartz veins is a quartz diorite phase of the Catface intrusions of Eocene age.

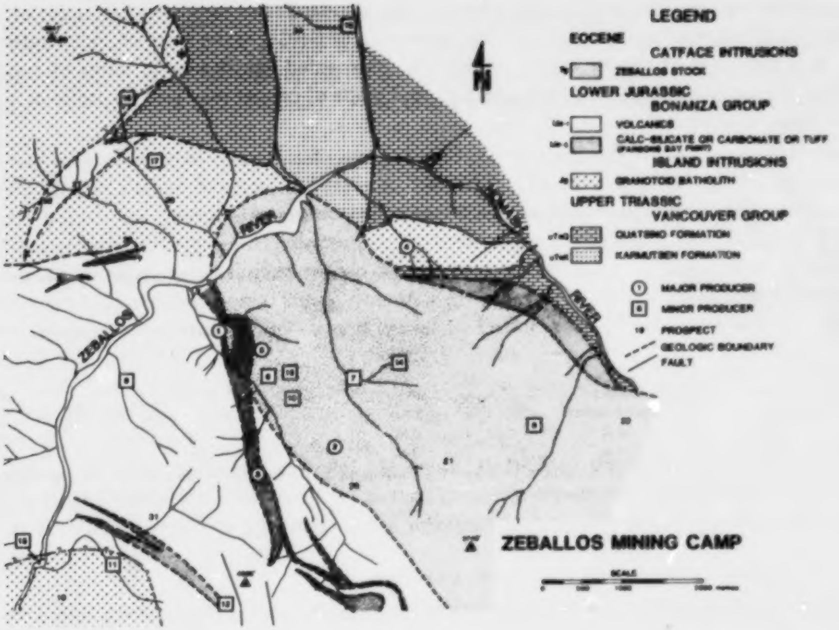

Figure 88. General geology of the Zeballos mining camp (modified from Stevenson, 1950).

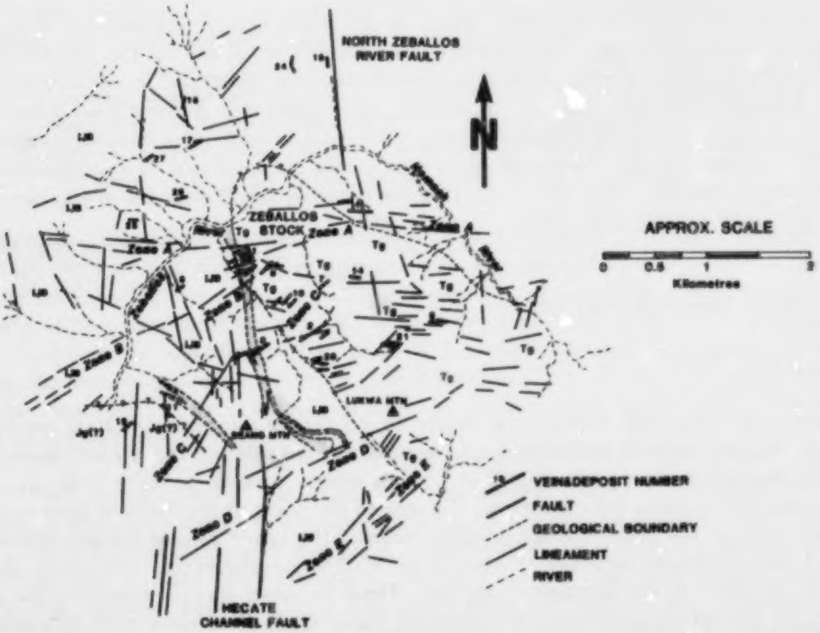

Figure 89. Fracture trace diagram from Zeballos mining camp as interpreted from aerial photographs. Scale is approximate because aerial photographs were used as a base. Several geological features are included as an aid to correlating this figure with Figure 88.

## STRATIGRAPHY

On Figure 88 the Bonanza Group is shown to contain units of carbonate, calc-silicate, and tuff. According to Dr. J. E. Muller (personal communication, 1982), these units almost certainly represent the Parson Bay Formation; that is, these units would represent the northwest continuation of the formation as shown on the 1:250 000 map of Nootka Sound (*Geol. Surv., Canada*, Map 1537A, 1981). The contact between Parsons Bay Formation and Bonanza Group is known to be gradational, as it would appear to be here. The Bonanza Group elsewhere on Vancouver Island is not known to contain any carbonate horizons, although sedimentary units do occur. The calc-silicate rocks adjacent to the Zeballos stock presumably represent contact metamorphosed carbonate or carbonate-rich sediment. If indeed these units are Parson Bay Formation, the implication is of a more complex structure than was previously thought to exist. The two horizons of Parson Bay Formation to the west of the stock seem to be a structural repetition. This would suggest either a tight, doubly plunging syncline or fault-controlled repetition. The latter explanation is favoured because there is no evidence of folding, in terms of the attitude of the bedding or of repetition of the underlying Vancouver Group.

In the extreme southwest of the map-area (Fig. 88) Stevenson (1950) has mapped a body of gabbro which contains the Answer and Golden Portal deposits. This gabbro contains fragments and boulders of unreplaced and partially altered volcanic rocks and is cut by diorite and granodiorite dykes which also cut the Zeballos stock and perhaps the Island Intrusions. Compositionally it is distinct from the hornblende diorite of the Island Intrusions in that it contains "...labradorite instead of andesine, and considerable augite with only a minor amount of primary hornblende" (Stevenson, 1950). The presence of pyroxene rather than hornblende suggests the possibility that this may be a feeder dyke (that is, subsurface equivalent) to the Bonanza volcanic rocks, or to higher level Tertiary volcanic rocks which have since been eroded. It is of interest to note that there are three gold producers in the immediate vicinity (Tagore, Golden Portal, Beano). It is generally accepted that gold-quartz vein mineralization is intimately related to Tertiary intrusions (for example, Carson, 1968) on Vancouver Island, yet the Zeballos stock is 2 to 3 kilometres away. In addition, a replacement deposit such as the Beano could be expected to lie quite near the source of mineralization. Thus it is at least possible that this gabbro is of Tertiary age.

There appears to be a close relationship between young dykes of a particular composition and the gold-quartz veins. Dykes which are the last phase of, or younger than, the Zeballos stock intrusion are of particular significance. Feldspar porphyries are intimately asssociated with the veins; a stock of feldspar porphyry occurs within the Mount Zeballos mine area. Orthoclase-rich granodiorite dykes are associated with mineralization at the Privateer and Central Zeballos deposits.

## FAULTING

Faulting in this and surrounding areas seems to have been the major structural response to deformation (Muller, Northcote, and Carlisle, 1974). With this in mind a fracture trace diagram, reproduced here as Figure 89, was compiled from 1:20 000-scale black and white aerial photographs, taken in August 1980. Because of the empirical nature of such data and the limited time available, only the major or obvious lineaments have been shown. In addition, the compilation has not been corrected for distortion. Our inability to check the features on the ground is a significant drawback to our interpretation of lineaments. Figure 90 is a rose diagram of all lineaments whereas Figure 91 shows only those lineaments greater than approximately 600 metres in length. This division was chosen by examining a histogram of all lineaments. Lengths up to about 600 metres define a normal population; lengths greater than 600 metres are a pronounced 'tail' to this 'normal' population.

The distinct concentration in both figures at azimuths of 150 to 190 degrees is thought to represent the continuation of the pre-Tertiary Hecate Channel fault of Muller, Cameron, and Northcote (1981). This fault has been mapped on Bingo and Friend Creeks by Hoadley (1953). The lineaments continue north

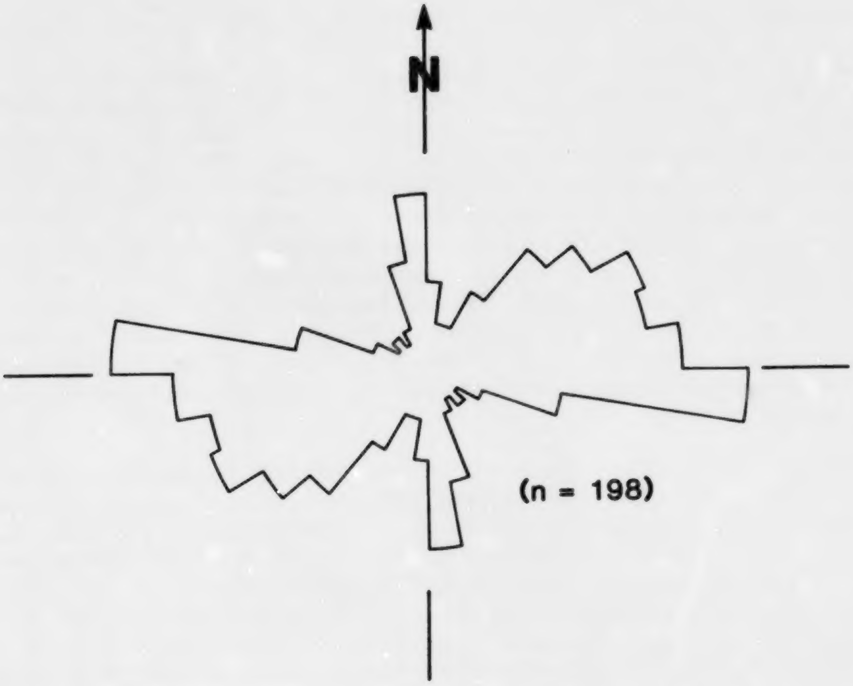

Figure 90. Rose diagram of all fracture traces shown on Figure 89.

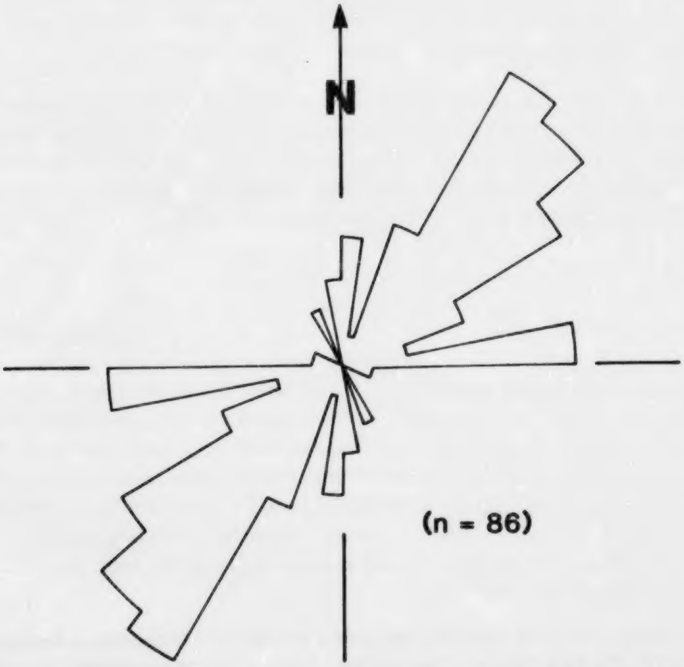

Figure 91. Rose diagram of fracture traces longer than 600 metres as they appear on Figure 89.

from these creeks and from the east side of the lower reaches of the Zeballos River. It is thought that Hecate Channel fault continues, offset, on the north side of the Zeballos stock as the north Zeballos River fault. These faults and the accompanying lineaments are considered pre-Tertiary as the faults are offset across the Zeballos stock and north/south lineaments are rare within the stock. This conclusion is in agreement with Muller, *et al.* (1981).

Some of the lineaments representing Hecate Channel fault pass between the two horizons of Parson Bay Formation. Gunning (1932) considers the north Zeballos River fault has been downthrown to the east. The same sense of movement on the fault to the southwest of the stock (that is, continuation of the Hecate Channel fault) would explain the repetition of the Parson Bay Formation.

Most of the lineaments fall within a large, rather poorly defined population between 030 and 100 degrees, as shown on Figure 90. Part of this population probably represents second order faults related to the previously discussed north-trending faults. Numerous east/west trending, generally short, lineaments occur within the Zeballos stock; these might be related in part at least to cooling of the stock. A well-developed fracture pattern in outcrop is diagnostic of the Catface intrusions (Muller, personal communication, 1982). It is possible that such fractures may correlate, in part, with the aforementioned set of east/west lineaments for the Zeballos stock. If such a correlation was found to be general throughout the area fracture trace analysis could well prove a fast and accurate method of determining 'age' of particular intrusions.

Of the remaining lineaments, many fall within relatively well-defined zones, shown as zones A to E on Figure 89. Zone A, passing through the Privateer and central Zeballos deposits, appears to represent a fault zone which has offset the north part of the Zeballos stock to the west. Zone A corresponds with a concentration of east/west-striking granodiorite dykes at central Zeballos. Lineaments in Zone A are well defined on the photographs, however there is no mention of such a fault by workers in the area. Zones B to D define four groups of lineaments striking 40 to 60 degrees and located to the west of the stock. They may offset the Hecate Channel-North Zeballos River faults. In any event lineaments of Zones A to E appear to all represent the same age of faulting or shearing and may all correlate with Eocene or later faulting, that is, syn- (or post-) intrusive.

## VEIN ORIENTATION

The strain ellipsoid of Figure 92 is modified after Stevenson (1950). On the basis of two major shears at Zeballos Pacific (035 degrees) and Big Star (090 degrees), along with some supporting data, he has concluded that planes of major shearing are oriented 035 degrees vertical and 090 degrees vertical. He derives

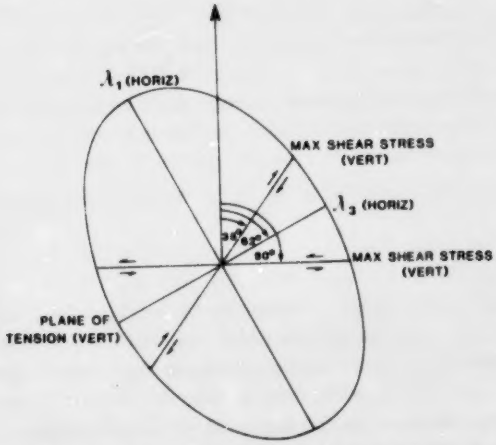

Figure 92. Strain ellipsoid for Zeballos mining camp.

062 degrees vertical to the plane of tension. He concludes that this latter orientation is most important with respect to vein orientation and mineralization, "fractures and consequently veins formed under tension are the most favourable for ore ..." (80 to 90 degrees) correlating well with Zones A to E of Figure 89 (040 to 060 degrees, 80 to 100 degrees). An example of rotational strain, using a shear direction of 085 degrees is illustrated on Figure 93. This example may be related directly to Zone A of Figure 89 and No. 1 and No. 2 veins of the Privateer deposit. Brecciation and shattering can be expected under low confining pressures, as is indeed the case at the camp. In other areas, the conjugate shear is more prominent (namely, Zones B to E of Figure 89).

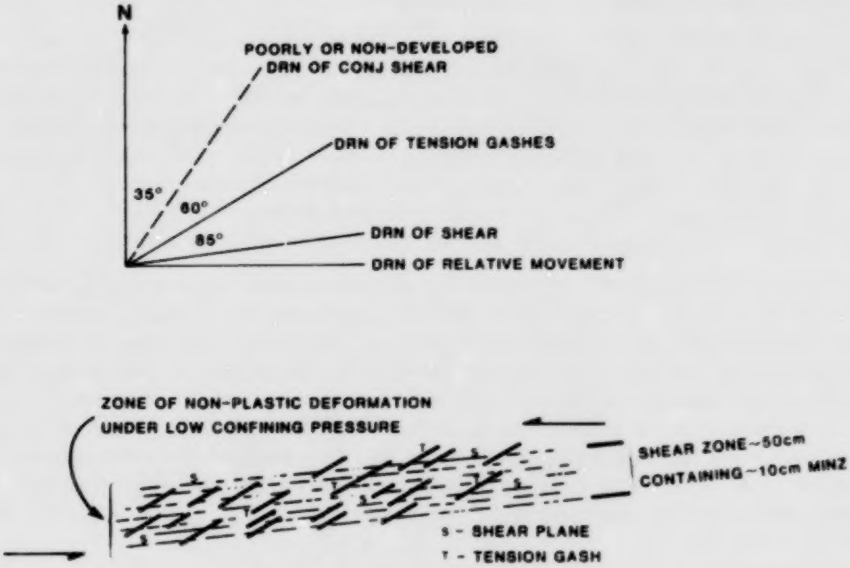

Figure 93. Conceptual model for development of veins and related structural features, Zeballos mining camp.

## NOSE OF STOCK

There is a strong correlation between the northwest nose of the Zeballos stock and mineralization. In a general way the greater the distance from the nose, the fewer the deposits and the less productive they have been. This is presumed to be a result of the extensive faulting and shearing in the vicinity of the nose providing the best pathways for ascending metal-bearing solution. Naturally there are other relationships which obscure the picture to a certain extent, such as that between metal content and distance to the intrusive contact. A complicating factor may be the gabbro in the southwestern part of the map-area, if this is Tertiary in age.

## VEIN WIDTH

Most productinve veins show a wide range in width (for example 1 to 100 centimetres), but the bulk of such veins usually shows considerably less variation (for example, 10 to 30 centimetres). The latter variation is described, rather arbitrarily, as typical minimum and typical maximum vein width. Typical minimum vein width is of considerable empirical significance. In general terms, productive veins can be expected to have a typical minimum width of around 1 to 5 centimetres along with a relatively small variation in width. There does not seem to be a correlation between vein width and width of the enclosing shear zone.

## HOST ROCK

Host rock to the veins includes all rock types in the area. Particular host rock type appears to have no influence on localization of veins, except insofar as the physical properties of the rock determine how it will react to deformation. Flexures appear to be favourable sites for mineralization, particularly in what is inferred to be Parson Bay Formation (for example, at Privateer and Mount Zeballos). Elsewhere on Vancouver Island the Parson Bay Formation is seen to be complexly folded, presumably because it reacts in an incompetent manner to deformation. The Bonanza volcanic rocks could be expected to react in a more brittle manner to deformation, thus more readily providing pathways and sites of deposition for migrating hydrothermal solutions. The presence of sharp bends or curves in the margins of the stock are also likely loci of deposition, as are areas of shattering and brecciation.

## ASSOCIATED MINERALS

The sulphide assemblage characteristic of gold-quartz vein occurrences on Vancouver Island (for example, Bancroft, 1937; Muller and Carson, 1969; Carson, 1968) is pyrite, sphalerite, galena, and chalcopyrite. Arsenopyrite may be present and pyrrhotite is relatively uncommon. There is a strong negative correlation between chalcopyrite (GRCU) and total gold among the producers as discussed earlier. Arsenopyrite, alone, does not seem to be related to gold content, however if present in measurable quantity along with sphalerite, galena, and chalcopyrite there generally is associated high-grade (150 to 3 000 grams per tonne) gold. Quartz is ubiquitous, calcite locally accompanies mineralization, and ankerite is rare.

## EXPLORATION PARAMETERS

The following parameters are intended to be applied to known vein(s) under investigation at Zeballos camp. However, it would not be unreasonable to extrapolate the use of some parameters to similar veins elsewhere on Vancouver Island. It should not be assumed that these are the only factors influencing economic mineralization or that the interpretation of these observations is necessarily unique.

(1) Spatial association of gold-quartz veins with the Eocene Catface intrusions is of primary importance. The best economic potential seems to be within 500 to 1 000 metres of the contact of intrusive bodies greater than 2 000 metres in diameter.

(2) Brecciation of the intrusive and/or host rock, along with pre-existing or contemporaneous faulting, aids in establishing pathways for the hydrothermal fluids.

(3) Close association with late or post-Catface intrusion dykes is a favourable feature, in particular, (quartz) feldspar porphyry dykes and stocks.

(4) Host rock type is important insofar as its physical properties determine its response to deformation. For example, fracturing on fold crests may, in association with other factors, provide a suitable locus of deposition.

(5) A folded or convoluted margin to the intrusion, or apophyses, might be expected to aid in the localization of mineralization.

(6) The orientation of the vein and its enclosing shear, if present, along with intersecting shear zones, is of considerable importance. At Zeballos rotational strain apparently produced shears orientated at 035 to 060 degrees and 080 to 090 degrees (Fig. 94). When allied with tensional cavities and gash veins, they may have provided suitable sites for deposition of economic mineralization (Fig. 95).

(7) The sulphide assemblage should include pyrite, galena, chalcopyrite, and sphalerite with or without arsenopyrite.

(8) Average copper grade may be used as an aid in predicting potential total gold present. If substantial sample data are available a multivariate linear model relating size to copper, lead, silver, and gold grades can be applied.

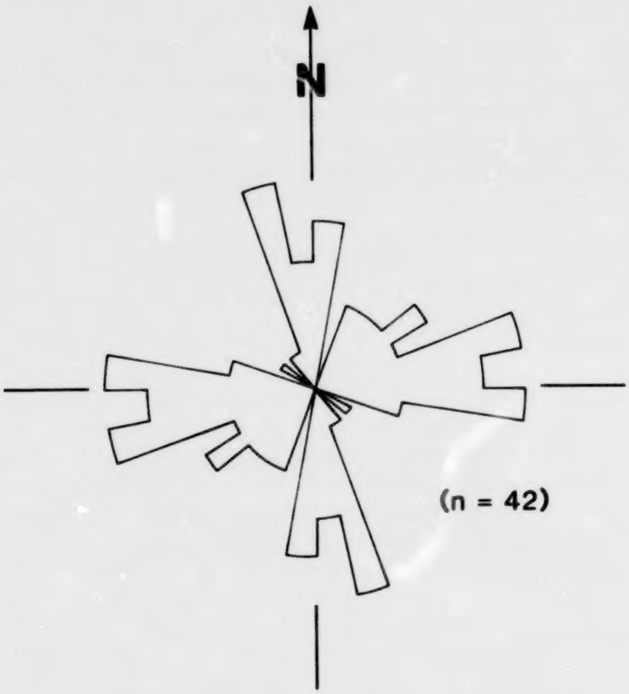

Figure 94. Rose diagram of vein orientations, Zeballos mining camp.

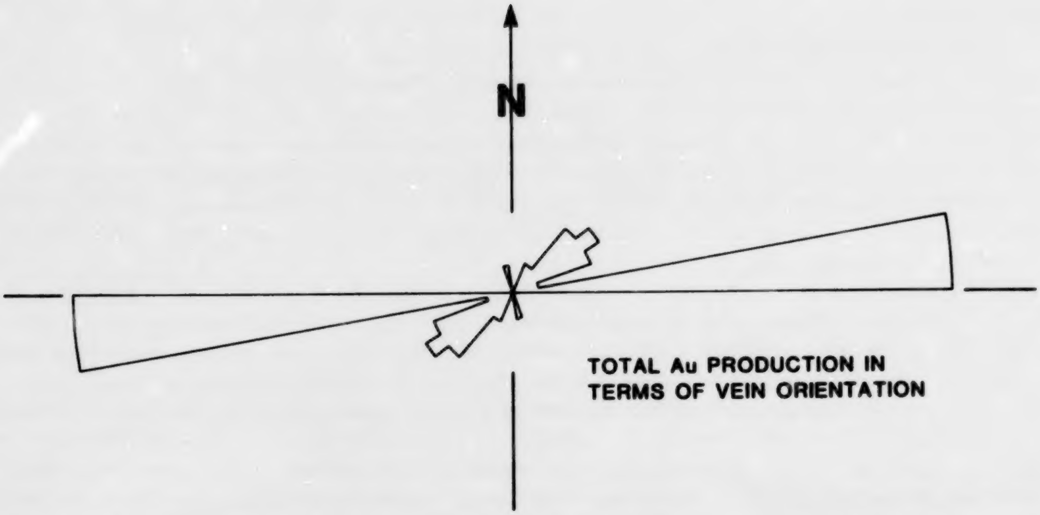

Figure 95. Rose diagram of total gold production as a function of vein orientation, Zeballos mining camp.

The area of Zeballos camp is roughly 5 000 hectares and it might be thought that all veins in such a restricted area already have been discovered and exploited. However, aside from the possibility of a concealed mineralization, the rugged topography of the area, heavy vegetation, superficial cover on bedrock and the small size of the target may have prevented discovery of veins containing potentially economic minerals. In reference to the search for the White Star veins, Bancroft (1940) says "Half a dozen prospectors searched the slopes for 4 months before finding the quartz in place .... 500 or 600 feet above the bed of the creek". This was after having found "...rich gold quartz float with granitic rock attached..." in Spud Creek almost directly below the veins. It would seem that even today there exists opportunity for new vein discoveries.

Alternatively, it may be that past producers have not been exploited fully, or non-productive prospects may have the potential to become producers; our work is somewhat negative in this regard. Finally, it is important to mention that we have considered gold in quartz veins only. Other deposit forms (skarn, replacement) may have potential in the Zeballos camp.

## ACKNOWLEDGMENTS

This study, financed by the Science Council of British Columbia, is part of the MINDEP research project of the Department of Geological Sciences, University of British Columbia. It has been undertaken with the cooperation of the Geological Division, British Columbia Ministry of Energy, Mines and Petroleum Resources. We would like to thank J. E. Muller of the Geological Survey of Canada for his advice and general comments. Technical assistance has been provided by A. Bentzen. P. Wilton, British Columbia Ministry of Energy, Mines and Petroleum Resources, kindly provided a set of aerial photographs for our study.

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# A PRELIMINARY REPORT ON RESOURCE ESTIMATION USING GRIDDED GEOLOGICAL DATA
# I: GUICHON CREEK BATHOLITH
## (92I/6, 7, 10, 11)

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## INTRODUCTION

Many quantitative resource-oriented studies are based on geological variables quantified with respect to cells of a regular grid superimposed on a geological map of an area. Cell size of the grid varies with the purpose and scale of a study as well as the detail with which geological information is known. In a regional study of British Columbia copper resources Kelly and Sheriff (1969) used a 20 by 20-square-mile cell whereas Sinclair and Woodsworth (1970) used a 2 by 2-square-mile cell size for an estimation of vein potential in the Terrace area of northern British Columbia, and Godwin and Sinclair (1979) extended the methodology to a grid cell size of 400 by 400 square feet over the Casino porphyry copper-molybdenum deposit, Yukon Territory.

The types of variables we are concerned with in quantitative, geology-based regional resource studies include:

(1) percentage of a cell underlain by a particular rock type,
(2) distance from cell centre to a specific geological feature,
(3) spatial density of dykes, fractures, and other features,
(4) lengths of contacts, dykes, and fractures contained within a cell,
(5) surface area of the contiguous mass of a given rock type nearest a given cell.

Agterberg (1981) discusses the form of the probability density functions of these types of variables. One of their principal features is the large number of zero and 100 per cent values that result for variables of the type involving 'per cent of a cell underlain by a specific rock type'.

The present study has two specific goals:

(1) to develop a general, computer-based approach for the estimation of quantitative geological variables as a basis for studies of regional mineral resource potential, and
(2) to apply the foregoing computer-based methodology to the Guichon Creek Batholith, host for an important proportion of known copper resources in British Columbia.

## PROCEDURE

A general procedure for a quantitative computer-based approach is given by Sinclair and Bentzen (1983). Two general stages are as follows:

(1) quantification of geological variables using a computerized approach, and
(2) application of an appropriate mathematical approach to an evaluation of the quantitative data base.

The former step involves digitizing and editing of map information, and application of a series of computer programs to measure geological variables relative to an arbitrary grid. The latter step depends to a considerable extent on subjective decisions. A general methodology for quantification of geological variables, illustrated by Sinclair and Bentzen (1983), emphasizes the digitizing and calculation phases.

The principal advantages of a computer-based procedure are its consistency, the ability to build in a variety of editing procedures to detect errors in the data base, and the ease with which new variables can be added or old variables changed. The ease with which a completely new set of variables can be generated for a new cell size or a new grid origin of a grid is particularly noteworthy.

Once the data are available a set of control cells must be selected; these are used to generate a mathematical model for value or potential in terms of the measured geological variables. Multiple regression, discriminant function analysis, and a variety of probabilistic procedures have been used as a means of developing such models (Agterberg, 1981). Here we will stress a multiple regression model in which known mineral resources within a cell represent the dependent variable and our measured geological variables (appropriately transformed if necessary) are the independent variables. Once a satisfactory model has been established for the control cells, it is applied to the remainder or target cells as a means of estimating their mineral potential.

## DIGITIZING GEOLOGICAL INFORMATION

Digitizing of geological information (outlines of areas underlain by rock types, linear features, etc.) proceeds as follows:

(1) In general, a contact is traced with the digitizer cursor completely around a given geological feature.

(2) Enough points are digitized so that the resulting polygon appears to be a smooth representation of the original outline when plotted at the original scale.

(3) Each polygon is numbered and catalogued.

(4) The number of a polygon is placed in the comment field of the first point of that polygon.

(5) If any point along a polygonal outline represents an intersection or 'meeting' of contacts, that point is labelled as a node in the comment field.

If a digitizing error is made by an operator it is often possible to return to the nearest node, begin digitizing again, and edit out the error segment.

A digitizing program was written in FORTRAN IV using University of British Columbia system subroutines to read the cursor of the digitizer. The program corrects for displacement from the origin and for skewness (where the map has not been placed parallel with the x and y axes of the digitizer). A digitized point is read into memory where it is stored until output as a file. Each digitized point corresponds to a record consisting of four fields as follows:

| FIELD | DESCRIPTION |
|---|---|
| 1 | 4 characters (MOVE, DRAW, or SAME) |
| 2, 3 | x and y coordinates written in FORTRAN FORMAT (2G15.7) |
| 4 | Comment field of 8 characters |

The operator can choose freely when to use the comment field.

## EDITING OF POLYGONAL (DIGITIZED) INFORMATION

Three procedures are used for editing digitized polygonal information. Two, ADEND and EDTEK, are programs written by one of us (A.B.), the third is the text editor supplied by the operating system (MTS). In a digitizing session a number of polygons normally would be placed in the same file. The first part of the editing process is to assign polygons to separate rock type files.

The editing program presents one polygon at a time to the operator and ADEND allows the operator to assign a 'flag' to separate polygons. ADEND is used on a TEKTRONIX 4010. The operator selects the number of points to be displayed on the terminal by a trial-and-error process and isolates a polygon – a flag is then added and the operator continues with the next polygon. During this phase of editing it is possible to 'repair' errors in the digitizing process (for example, the deletion of erroneous segments). In addition, polygons must be closed for future use so it is important to verify that the last and first points are identical. Finally, the nature of area determination program is such that digitizing should be in an anti-clockwise direction. Consequently, at this stage any polygons digitized in a clockwise direction must be reversed.

EDTEK is used on a TEKTRONIX 4010 and permits the display of polygons as well as a limited amount of editing. One point or several points at a time can be moved back and forth through a polygon thus allowing repair of digitized lines. In addition, plotter directives can be changed; for example, 'MOVE' can be changed to 'DRAW'. Another plot directive 'NOPE' (meaning NON-OP) was added which effectively eliminates a point without actually deleting the coordinates.

At this point in the editing there should be one file for each geological variable. In the case of a rock type, the file contains as many polygons as there are separate outcrop areas. A program CHKPL is used to verify that each polygon is constructed in a counter-clockwise manner.

A final editing stage involves the recognition of 'islands' of a second rock category within a polygon surrounding an area of a different rock category. These 'islands' were coded as clockwise polygons attached to the perimeter of the surrounding polygon.

An example of edited polygons is given by Sinclair and Bentzen (1983) for the border phase of the Guichon Creek Batholith.

## MEASUREMENT OF GEOLOGICAL VARIABLES

All variables are to be measured relative to individual cells of an arbitrary grid superimposed on a field of geological data. The types of variables referred to earlier (*see* Introduction) include area measurements, length of line segments, and distance to nearest expression of a geological feature, measured respectively by a series of subroutines named AREA, LCON, and DCON.

AREA is an area calculating program that utilizes a 'point counting algorithm'. Each cell of a grid superimposed on the area in question is represented by an array of 400 subcells (points). The program determines for each cell, the proportion of subcells that are contained inside or outside the polygons of a particular rock type. A subcell was assigned '0' if it lies outside a polygon and '1' if it lies within a polygon. The array of 0's and 1's were stored and area calculated by simple counting. In the early stages a listing of the array was used as a check on the procedure and programming. In a few cases of highly irregular outcrop shapes, the inefficiency of the AREA algorithm necessitated subdivision of a complex polygon into several smaller simple polygons.

DCON calculates the distance from the centre of a cell to the nearest contact of a selected rock type. Each cell in turn is checked against a current polygon.

## TABLE 1
## VARIABLES AND TRANSFORMATION USED IN THE REGRESSION ANALYSIS

**(Variables considered but not used are omitted from the list.)**

| | VARIABLES | TRANSFORMATION | COMMENTS |
|---|---|---|---|
| 8 | distance[1] to Bx | arith, stand[3] | Breccia |
| 9 | distance to 4 | arith, stand | Bethlehem phase granodiorite |
| 10 | distance to 4a | arith, stand | Bethlehem phase granodiorite |
| 11 | distance to 5a | arith, stand | Skeena variety granodiorite |
| 12 | distance to 5 | airth, stand | Bethsaida phase quartz monzonite to granodiorite |
| 13 | distance to 5b | arith, stand | Bethsaida phase quartz monzonite to granodiorite |
| 17 | length[2] of 2 | arith, stand | Border phase quartz diorite to granodiorite |
| 24 | length of 4 | arith, stand | Bethlehem phase granodiorite |
| 25 | length of 4a | arith, stand | Bethlehem phase granodiorite |
| 26 | length of 5a | arith, stand | Skeena variety granodiorite |
| 27 | length of 5 | arith, stand | Bethsaida phase quartz monzonite to granodiorite |
| 28 | length of 5b | arith, stand | Bethsaida phase quartz monzonite to granodiorite |
| 46 | area[4] of sum of 2, 2a | arcsine | Border phase quartz diorite to granodiorite |
| 47 | area of sum of 3a, 3b, 3c, 3d, 3e | arcsine | Guichon variety, Chataway variety, and Transitional granodiorite |
| 48 | area of sum of 4, 4a | arcsine | Bethlehem phase granodiorite |
| 49 | area of sum of 5a, 5, 5b | arcsine | Skeena variety granodiorite and Bethsaida phase quartz monzonite to granodiorite |
| 54 | distance to Ex4[5] | arith, stand | Bethlehem phase granodiorite |
| 55 | distance to Ex5a | arith, stand | Skeena variety granodiorite |
| 56 | distance to Ex5 | arith, stand | Bethsaida phase quartz monzonite to granodiorite |
| 57 | length of Ex2 | arith, stand | Border phase quartz diorite to granodiorite |
| 61 | length of Ex4 | arith, stand | Bethlehem phase granodiorite |
| 62 | length of Ex5a | arith, stand | Skeena variety granodiorite |
| 63 | length of Ex5 | arith, stand | Bethsaida phase quartz monzonite to granodiorite |
| 71 | sum of area of 2a, Ex2 | arcsine | Border phase quartz diorite to granodiorite |
| 72 | sum of area of 3a, Ex3b, 3c, Ex3d, Ex3e | arcsine | Guichon and Chataway variety granodiorite, and Transitional granodiorite |
| 73 | sum of area of Ex4, 4a | arcsine | Bethlehem phase granodiorite |
| 74 | sum of area of Ex5a, Ex5, 5b | arcsine | Skeena variety granodiorite and Bethsaida phase quartz monzonite to granodiorite |
| 75 | distance to Lornex fault | arith, stand | |
| 77 | grade of copper of deposits | log | |
| 88 | whole rock copper content | log | |
| 89 | whole rock zinc content | log | |
| 90 | geomagnetic field strength | arith, stand | |
| 94 | difference in geomagnetic field strength | log | |
| 95 | distance to wallrock | arith, stand | |

---

[1] 'Distance' means the distance from centre of cell to nearest contact with one of above rock types.

[2] 'Length' means length of contact of each of above rock types within each cell.

[3] 'Arith, stand' means arithmetic, standardized, that is, the mean value of a variable is subtracted from a given value and the result is divided by the standard deviation.

[4] 'Area' means fraction of area of each cell underlain by each of above rock types.

[5] 'Ex' means that the contact of this rock unit was extensively extrapolated across under or overlying sedimentary and volcanic rocks.

LCON measures the length of a particular rock contact within a given cell. The procedure is to measure the distance between successive pairs of points in a polygon, determine which cell the points are in, and cumulate length until a point is found outside the current cell. For a given variable each polygon is treated in succession, and within each polygon points are examined successively. For two points that straddle the boundary of adjoining cells no attempt is made to distribute the distance between cells. This is not a problem where distance between points is small compared with cell dimensions.

Verification of measured geological variables is achieved by plotter output of the measurements at a scale that can be overlain on the base geological map.

## APPLICATION TO THE GUICHON CREEK BATHOLITH

Geological variables for the Guichon Creek Batholith were digitized as outlined previously using as a base the most recent publically available geological map of the area (McMillan, 1978). Variables quantified and found useful are listed in Table 1. All variables were examined as histograms and probability graphs and most were transformed to a closer approach to normality as indicated in Table 1.

A control area consisting of 32 cells was selected to include a geologically representative transect across the batholith that included the major mineral deposits. Measures of cell value were estimated by copper reserves and production taken largely from Sinclair, *et al.* (1982). Within the transect, cells with no known copper content were assigned a value of 1 000 tonnes for most of our studies; a non-zero value was required because the value variable (tonnes of copper) was log transformed.

Backward stepwise multiple regression was conducted for the 32 control cells with tonnes of copper (log transformed) as the dependent variable and various groupings of geological variables (approximately transformed, Table 1) as independent variables. Relatively simple equations were eventually established after considerable trial and error on (1) variations in assumed copper content of 'zero' reserve cells, (2) the effects of different transformations of some independent variables, and (3) sensitivity studies on the inclusion and omission of several independent variables. A final model for this phase of the study is listed in Table 2.

**TABLE 2**
**MULTIPLE REGRESSION EQUATION FOR**
**COPPER RESOURCE ESTIMATION**
**GUICHON CREEK BATHOLITH**

$$
\begin{aligned}
\mathrm{Log}^{10}\ (\text{tonnes copper}) = 1.2752 &+ 0.7623\ (\text{magnetic field relief}) \\
&- 0.8231\ (\text{distance to breccia}) \\
&- 1.1351\ (\text{area Chataway} - \text{Guichon}) \\
&- 0.3509\ (\text{length of contact of hybrid phase})
\end{aligned}
$$

$R^2 = 0.49$; Standard Error = 0.9117; variables significant at 0.05 level.

The regression model for cell value was then applied to the target cells and cell values were estimated as potential tonnes of concentrated copper. The model was used first to estimate cells underlain by known rock types, and secondly, to estimate copper potential in cells with younger volcanic cover where we had to interpolate geological contacts. Results are summarized on Figure 96. These results are subject to a considerable amount of uncertainty – the standard error of the model is about one order of magnitude, but a major source of unknown error also exists in the basic assumptions that a continuous relationship exists between tonnes of copper and a combination of geological variables, and that the control cells are truly representative. At this stage we can say that the variables included in the model appear reasonable from a geological point of view and that the model reproduces most known large copper reserves reasonably well (that is, within the error limits of the regression equation).

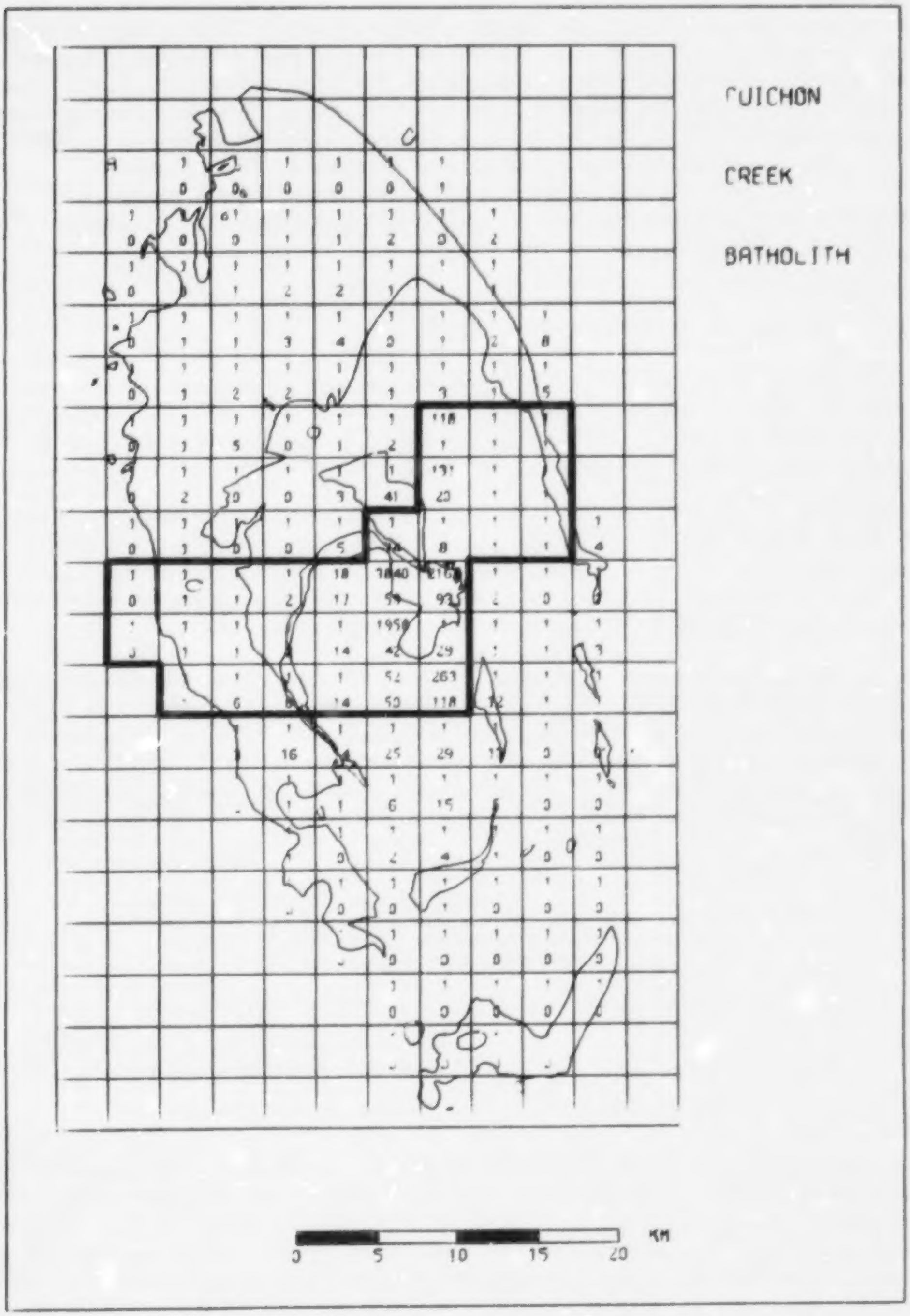

Figure 96. Two by 2-mile-squared grid cells superimposed on the Guichon Creek batholith. Control cells (30) are enclosed by a heavy rectangular outline. Figures in each cell refer to thousands of tonnes of copper observed (upper) and calculated by backward stepwise regression model (lower).

## DISCUSSION

This study clearly outlines the copper-rich central part of the batholith but also emphasizes several cells that appear to have high copper potential but no known reserves. One purpose of the study was to develop a methodology for recognizing areas now covered by younger volcanic rocks that have potential. The results are at least partially successful in this regard although unknown factors always leave an element of doubt.

The models we have developed require further testing using sensitivity tests; tests to examine the effects on the model of varying the size of the grid cell and the origin of the grid. Other mathematical models than multiple regression should also be attempted for the Guichon data base.

## ACKNOWLEDGMENTS

This study is part of the MINDEP project in the Department of Geological Sciences, University of British Columbia; it has been funded by the British Columbia Science Council with the continuing support of the British Columbia Ministry of Energy, Mines and Petroleum Resources.

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# TRIANGULAR GRAPHS
# AS AN AID TO METALLOGENIC STUDIES OF
# POLYMETALLIC VEIN DEPOSITS

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## INTRODUCTION

Triangular graphs are a common means of depicting relative variations of three components of multicomponent systems. They are commonly used in petrology and rock classifications, for example, where the components in question generally constitute a large proportion of the system. In geochemistry they may be used to compare trace element ratios for samples from one environment to another. In this latter application it is possible to plot variables that span several orders of magnitude, certainly one of the advantages of this form of graphical representation. One application of triangular diagrams in the field of ore deposits classification concerns porphyry-type deposits (for example, Kesler, 1973; Sinclair, *et al.*, 1982). These authors use triangular diagrams to show variations in metal ratios involving copper, molybdenum, gold, and silver in several groupings. In order to spread plotted points over a reasonable proportion of the triangular field some of these variables had to be multiplied by a constant. For example, in constructing a copper-molybdenum-gold plot Kesler (1973) transformed all variables to the same units and then multiplied copper by 1, molybdenum by 10, and gold by 10 000. These transformed figures were then recalculated to a pseudo 100 per cent for plotting purposes. This multiplication procedure is essential or all plotted points might be confined to a very small field (a point) or to one side of the triangular graph. Nevertheless, it is important to be aware that multiplying some of the components by different and large numbers has the effect of confusing our natural or automatic interpretation of the diagram. For example, in a triangular graph ABC, the line from A to the mid-point of side BC would normally be expected to represent a ratio for B:C of 1:1. If B has been multiplied by 1 000 and A and C have not, then the aforementioned line in reality represents a ratio of approximately 1 000:1. Obviously, such diagrams should contain labelled reference lines for important ratios.

## APPLICATION TO POLYMETALLIC VEIN CAMPS

In our studies of vein camps in southern British Columbia (for example, Sinclair and Goldsmith, 1980) we have found triangular diagrams a useful means of comparing production data from various camps. Data available to us at the time of our study were entirely in per cent (for lead and zinc grades) or ounce per ton (for gold and silver grades). Because of this, and because ratios involving precious and base metals commonly used in the exploration industry are in ounces of precious metal per per cent of base metal (ounce per per cent), we adopted the procedure of plotting triangular diagrams as follows: average grade figures were accepted as quoted (per cent or ounce per ton) and for any three figures (for example, lead, zinc, and silver) the figures were recalculated to 100 per cent assuming they were all the same units, that is, 28 ounces silver per ton, 7 per cent lead, and 5 per cent zinc would be recalculated to apparent percentages of 70 per cent silver, 17.5 per cent lead, and 12.5 per cent zinc.

The four vein-mining camps considered here are Ainsworth, Slocan (Sandon), Slocan City, and Trout Lake (Fig. 97). Each contains from 43 to 204 veins that have had at least one ton of production for which grade data are available in existing computer files (Orr and Sinclair, 1971; Read, 1976; Goldsmith and Sinclair, 1983; and MINFILE) that have been updated and edited by the writers.

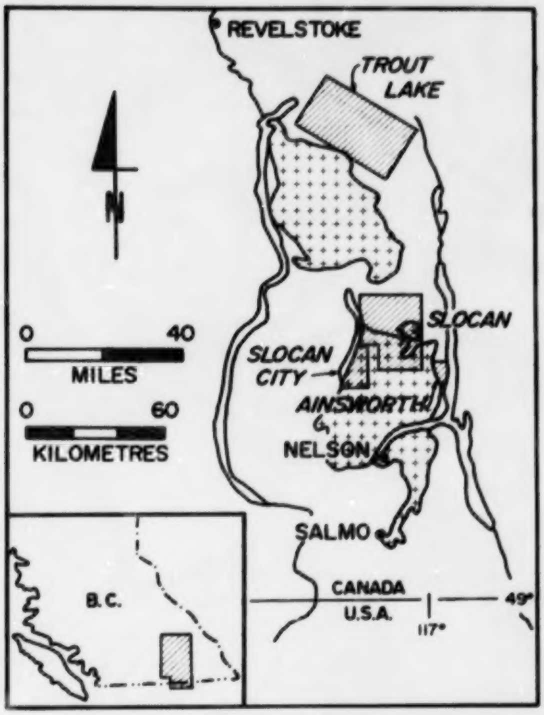

Figure 97. Location of Ainsworth, Slocan (Sandon), Slocan City, and Trout Lake silver-lead-zinc-gold camps, southern British Columbia.

**TROUT LAKE CAMP:** Triangular plots of average grade data for 43 past-producer vein deposits in Trout Lake mining camp are shown on Figure 98. The greatest spread of data appears in the silver-lead-zinc plot where all deposits for which these elements are available (n = 38) plot in about half the field represented by silver(ounce)/lead(per cent) ratios greater than about 0.7. In fact, only five of the 38 deposits have silver(ounce/lead(per cent) ratios less than one. Large tonnage deposits (greater than 600 tons production) are distinguished from moderate to low tonnage deposits by symbols and it is apparent from the plot that no distinction of metal ratio field exists as a function of production tonnage.

The other three plots of Figure 98 seem more effective in separating deposits into meaningful groups. In particular, Figure 98b and 98c clearly separate gold deposits from low to high tonnage silver deposits.

**AINSWORTH CAMP:** Mean grades of production from 75 veins in Ainsworth camp are shown on triangular plots on Figure 99. The silver-lead-zinc plot is dramatically different from that for Trout Lake camp. Data plot as two clearly defined clusters, one with relatively high silver(ounce)/lead(per cent) ratios (greater than one) which is comparable to Trout Lake camp and a second with much lower silver/lead ratios containing most of the deposits in the camp. A second difference from the Trout Lake camp is that a much greater proportion of Ainsworth deposits are zinc rich. Other plots of Figure 99 point to the very low gold content of Ainsworth silver-lead-zinc ores, comparable to the silver-lead-zinc ores of Trout Lake camp.

**SLOCAN (SANDON):** Average production grades for about 200 deposits from the Slocan (Sandon) camp are plotted as triangular diagrams on Figure 100. On Figure 100a virtually all deposits plot in little more than one-half of the triangular field with silver(ounce)/lead(per cent) ratio of greater than 0.7, comparable to silver-lead-zinc deposits from Trout Lake camp, and to a small subset of deposits from Ainsworth

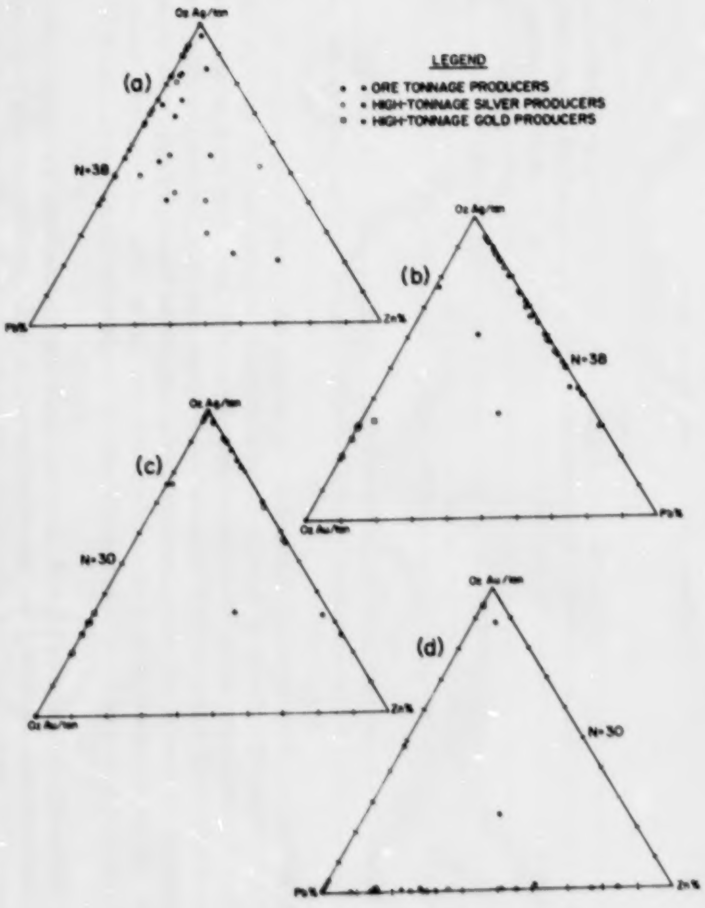

Figure 98. Triangular plots of average production grades for veins of Trout Lake mining camp.

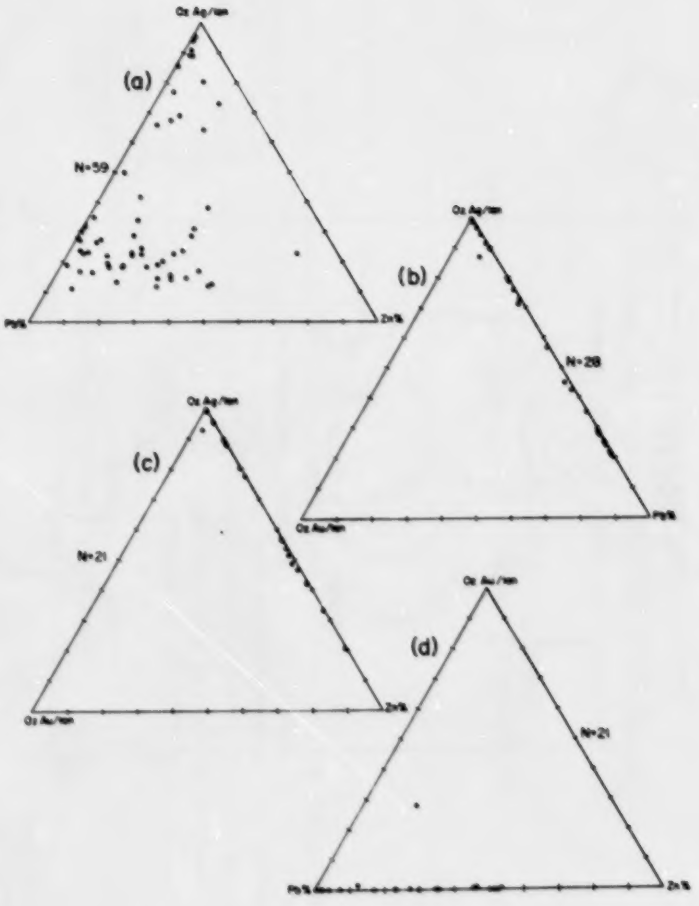

Figure 99. Triangular plots of average production grades for veins, Ainsworth mining camp.

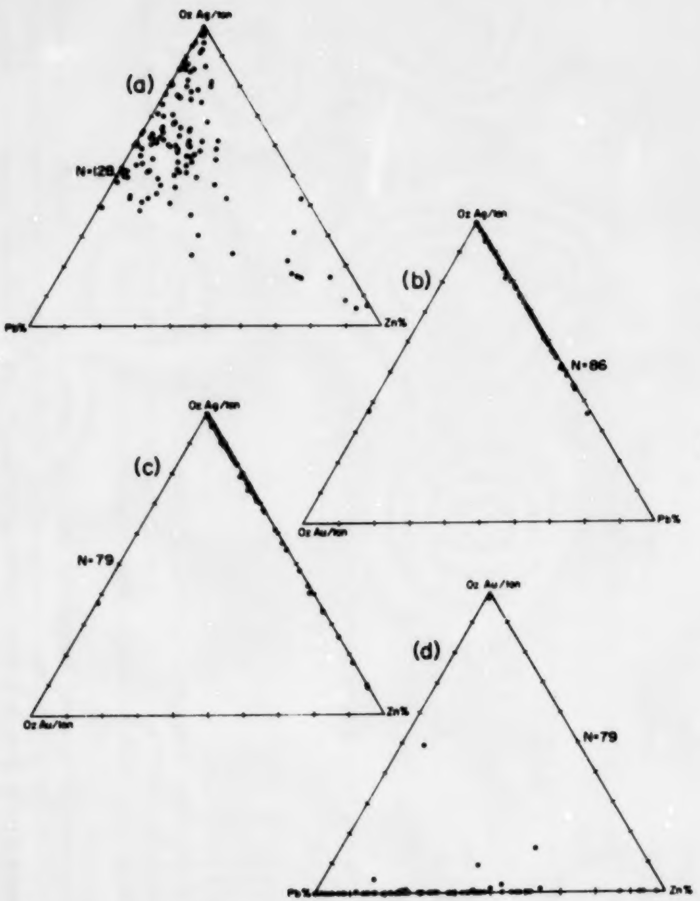

Figure 100. Triangular plots of average production grades for veins, Slocan (Sandon) mining camp.

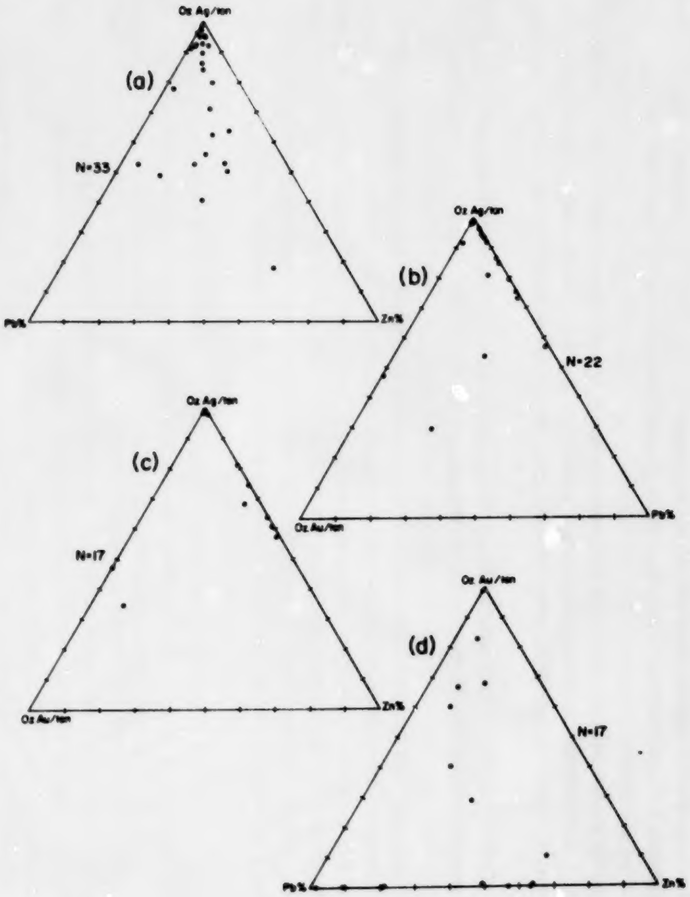

Figure 101. Triangular plots of average production grades for veins, Slocan City mining camp.

camp. Slocan ores differ slightly from the other two groups in that a significant group of zinc-rich deposits occurs and seems to form a separate grouping within the high silver(ounce)/lead(per cent) field.

The remaining triangular plots of Figure 100 demonstrate that, like silver-lead-zinc ores from both Ainsworth and Trout Lake camps, Slocan (Sandon) ores are low in gold. Furthermore, the presence of a high zinc population is emphasized by the presence of some plotted points near the zinc vertex of Figure 100c.

**SLOCAN CITY:** Average grade data for Slocan City polymetallic vein deposits are shown on Figure 101. The silver-lead-zinc plot is clearly comparable to the equivalent diagram for Slocan (Sandon) camp.

The remaining diagrams are based on sparce data sets but one in particular, the lead-zinc-gold plot of Figure 101d, shows that a large proportion (more than 40 per cent) of the plotted deposits are scattered throughout the triangular field rather than plotting along or very near the lead-zinc side. In this respect, Slocan City deposits differ clearly from Ainsworth and Trout Lake ores, and significantly, but to a lesser extent, from Slocan (Sandon) ores. This difference reflects the proportionately greater gold content of many Slocan City veins in comparison with veins from the other three camps considered.

## DISCUSSION

Triangular graphs are a practical means of utilizing quantitative chemical information (average grades of recorded production) as a basis for comparing or contrasting polymetallic mineral deposits in vein camps. They probably have a comparable use for portraying other types of polymetallic deposits. The examples studied here involved four polymetallic vein camps with quantitative production data for silver, gold, lead, and zinc. We found advantages in preparing all four possible combinations of the three metals as triangular plots, that is, silver-lead-zinc, silver-gold-lead, silver-gold-zinc, and gold-lead-zinc. Such plots can be obtained rapidly and cheaply as computer-generated plots from computer-based mineral deposit files.

Clustering of points is evident is some cases and differences from one camp to another become readily apparent. Of course, these differences represent relative proportions of various metals and give no indication of differences in absolute amounts.

One of the principal features that we observe is the common occurrence of a silver-rich group of deposits in all four camps, as shown by the occurrence of clusters towards the silver apex on the silver-lead-zinc plots. On this same plot Ainsworth stands out as being fundamentally different in terms of metal ratios because most deposits cluster in a low-silver field towards the lead vertex.

The other major contrast that we note is that Slocan City camp differs from the others in having a much higher proportion of deposits that are relatively enriched in gold.

From a metallogenic point of view the conclusions are of some interest. Slocan (Sandon) and Slocan City camps are clearly related in origin (LeCouteur, 1972) but are surrounded by totally different country rock. Slates, fine-grained quartzites, and tuffs occur in Slocan (Sandon) camp but plutonic rocks of the Nelson batholith predominate in Slocan City camp. It seems likely that country rock has exerted some control on metal content possibly due to: (1) changes in the fluid composition during transport through changing T-P conditions, or (2) local wallrock reaction at depositional sites.

The preponderance of low silver (ounce)/lead (per cent) values for Ainsworth deposits and the clear indication of relatively higher zinc values accentuates their differences from the other three camps examined. The difference is particularly striking in the case of Ainsworth versus Trout Lake because both camps occur in the same lower Paleozoic sequence (Lardeau Group); albeit rocks in the Ainsworth camp have undergone much higher grade regional metamorphism compared with the Trout Lake camp. Goldsmith and Sinclair (1983) suggested that in Ainsworth camp sulphides first accumulated as seafloor exhalites and subsequently were remobilized locally to form the numerous veins now known, a suggestion supported by lead-isotope data (Andrew, 1982). No clear-cut genetic model has emerged for Trout Lake deposits nor for deposits in the other two camps, although deposits in all camps are clearly epigenetic veins. Differences in metal ratios may reflect fundamentally different origins of the Ainsworth deposits.

Some degree of quantitative information can be retained in triangular graphs by using different symbols for different categories of deposits. We illustrate this for Trout Lake camp (Fig. 98) where three categories of deposits are distinguished by symbols; large tonnage gold deposits, large tonnage silver-lead-zinc deposits; and medium-to-small tonnage silver-lead-zinc deposits. An alternative practical approach might be to represent by one symbol all those deposits that exceed criteria for a minimum exploration target and to code all other deposits by a second symbol.

## ACKNOWLEDGMENTS

This work utilized data files to which major contributions were made by J.F.W. Orr (deceased) and P. B. Read; A. Bentzen assisted in obtaining computer output. The study is a by-product of a more extensive project on resource evaluation funded by the British Columbia Science Council in association with the MINDEP research project at the University of British Columbia and the British Columbia Ministry of Energy, Mines and Petroleum Resources.

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# GEOLOGY OF GYPO QUARTZ VEIN
# OLIVER, BRITISH COLUMBIA
## (82E/4)

By A. J. Sinclair, D. Moore, and A. Reinsbakken
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## INTRODUCTION

Gypo quartz deposit is in the Okanagan Valley near the northern outskirts of Oliver, British Columbia about 43 kilometres (27 miles) south of Penticton (Fig. 102). Production of high-purity silica was continuous from 1955, when development was taken over by Pacific Silica Company, until August 1968 when the operation was closed due to caving of part of the quarry wall. During this 14-year interval from 20 to 35 persons were employed annually. Yearly production ranged from a low of 2,500 tons in 1955 to a high of 60,000 tons in 1960. From 1962 to 1966 inclusive, average annual production was about 46,000 tons. At the close of continuous quarrying operations in 1968 more than 20,000 tons of crushed material of variable quality existed in stockpiles at the quarry site. Small shipments have been made since 1968, both from stockpiles and limited sorting of slumped material from the quarry floor. Most concentrates produced had a purity of greater than 99 per cent silica.

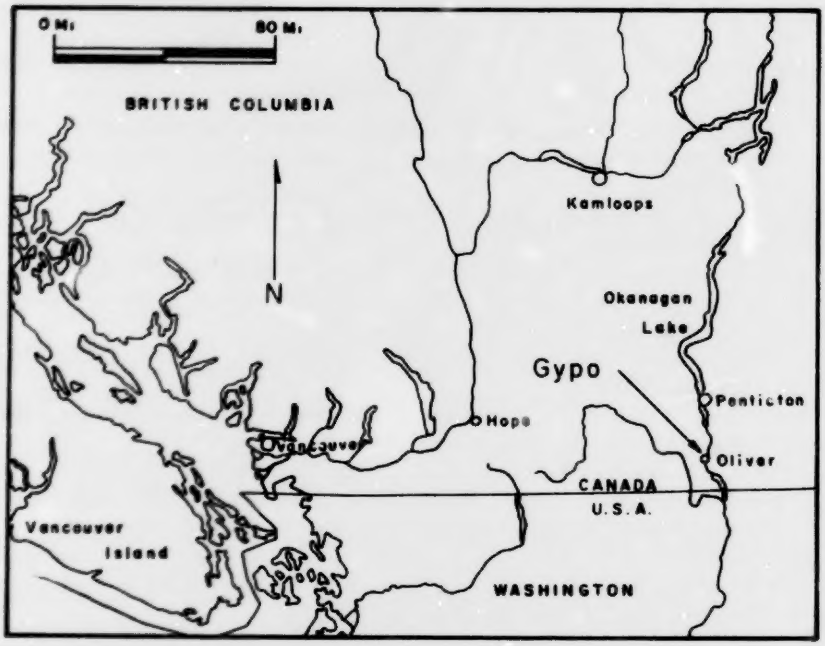

Figure 102. Location of Gypo deposit.

Production has been used mainly as decorative material in the building industry, especially as stucco dash. Small batches of concentrates have been used for a wide variety of purposes, including preparation of special cements, as a flux in the mineral industry, for patio aggregate, as poultry grit, in the production of ferrosilicon and silicon carbide, and others. Although Gypo vein has been quarried principally for quartz, a small amount of by-product fluorite has also been shipped from the deposit.

A number of other somewhat similar deposits occur in the general area. However, these are considerably smaller than Gypo deposit and were of interest in the past because of their precious metal contents. The nearest deposits of appreciable size are the Standard and Susie veins (Fig. 103), both of which have seen periodic reactivation in the past decade when gold prices have increased so dramatically.

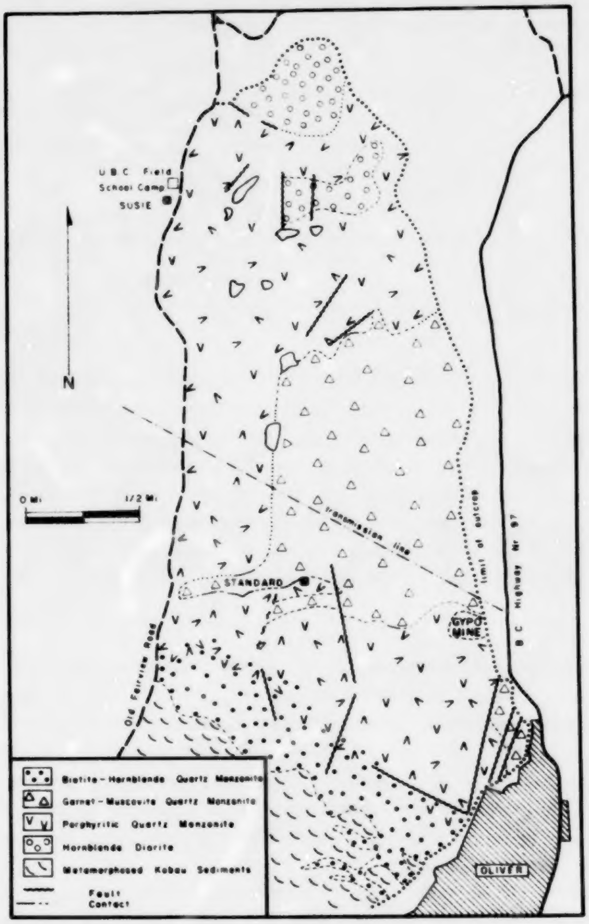

Figure 103. General geology of the Gypo deposit area.

Numerous small quartz veins and veinlets containing minor amounts of pyrite are known throughout the area. Morning Star and Stemwinder deposits of the Fairview camp (Cockfield, 1935) are in Kobau metasedimentary rocks several miles to the west.

## GENERAL GEOLOGY

The area surrounding Gypo deposit is underlain principally by medium-grained intrusive rocks that form what is here called the Oliver Plutonic Complex (Table 1). This complex includes rocks mapped previously as Oliver syenite and Oliver granite (Bostock, 1940). To the south the pluton cuts Kobau metasedimentary rocks of Carboniferous (?) age. On its northern margin the intrusive mass is in contact with Vaseaux Formation that probably is part of the Shuswap Terrane.

## TABLE 1
## MESOZOIC AND EARLY TERTIARY INTRUSIVE ROCKS NEAR GYPO DEPOSIT

| AGE | ROCK UNIT | ROCK TYPE | PREVIOUS TERMINOLOGY |
|---|---|---|---|
| EARLY TERTIARY | MAFIC DYKES | LAMPROPHYRE | |
| MIDDLE JURASSIC | OLIVER PLUTONIC COMPLEX | MUSCOVITE QUARTZ MONZONITE | OLIVER GRANITE OF BOSTOCK (1940) |
| | | PORPHYRITIC QUARTZ MONZONITE | |
| | | BIOTITE–HORNBLENDE QUARTZ MONZONITE | OLIVER SYENITE OF BOSTOCK (1940) |

Recent work (Fig. 103) shows that Oliver pluton is composed almost entirely of quartz monzonite (Richards, 1969). Three distinct phases can be recognized in the field. A central core of massive medium-grained garnet-muscovite quartz monzonite is surrounded by a porphyritic quartz monzonite containing about 1 to 5 per cent phenocrysts of K-feldspar up to 2.5 centimetres (1 inch) in maximum dimension. The contact between these units is commonly a narrow zone of quartz-feldspar pegmatite a few metres to 3.5 metres (10 feet) in width. However, at Gypo mine and at one locality along the northern margin of the core the contact is either sharp or gradational over several metres. Field examination indicates that the predominant mafic mineral in the porphyritic quartz monzonite is hornblende north of the core and biotite to the south.

The third phase of the pluton is a hornblende-biotite quartz monzonite located to the south of the other two units and previously referred to as Oliver syenite by Bostock (1940). A transition zone of up to 60 metres (200 feet) in width separates hornblende-biotite quartz monzonite from porphyritic quartz monzonite. Rocks in the transition zone are sub-porphyritic with smaller phenocrysts and a higher mafic mineral content than in the porphyritic quartz monzonite. The hornblende-biotite quartz monzonite contains numerous elongate mafic-rich inclusions that parallel a primary foliation of mafic minerals. Both of these features are most pronounced near the contact with Kobau metasedimentary rocks and the foliation, in general, seems to parallel the contact.

Relative ages of the three units have been determined from cross-cutting relations just west of the area shown on Figure 103. West of Old Fairview Road, immediately south of the powerline, dykes of garnet-muscovite quartz monzonite cut the porphyritic quartz monzonite. Similar relations are found further west. About 2.4 kilometres (1.5 miles) west of Old Fairview Road, along the general trend of the hornblende-biotite quartz monzonite unit, a thick dyke of porphyritic quartz monzonite cuts the hornblende-biotite quartz monzonite. Hence, on geological grounds relative ages of the three main phases of the Oliver pluton are: hornblende-biotite quartz monzonite (oldest), porphyritic quartz monzonite, and garnet-muscovite quartz monzonite (youngest). Modal analyses for specimens (*see* Table 2) of all phases are plotted on a feldspar-quartz triangular diagram (Fig. 104). A variety of dykes cut the pluton. Near the University of British Columbia geology field school is a swarm of fine-medium grained quartz monzonite dykes that cut hornblende-bearing porphyritic quartz monzonite. Similar but finer grained dykes are present in the southern part of the area. Along the northern margin of the core a small fine-grained muscovite-biotite-garnet-bearing dyke cuts both the porphyritic quartz monzonite and the garnet-muscovite quartz monzonite. Numerous dyke-like bodies occur in Kobau metasedimentary rocks along the southern margin of the pluton. Many of these are apophyses of the pluton but some are later dykes.

## TABLE 2. MODAL COMPOSITIONS

| SAMPLE NO. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Thin section no. | R68-2 | GYPO 4 | R68-1 | 567-15 | R68-5A3 | R68-5A1 | R68-5A2 | R68-5B3 | R68-5A1 | 567-1 |
| Hand specimen no. | R68-2 | G-4 | R68-1 | 567-15 | R68-5A | R68-5A | R68-5A | R68-5B | R68-5A | 567-1 |
| General description | unaltered | unaltered | unaltered K-Fp rich | K-Fp alteration | K-Fp alteration | K-Fp alteration | K-Fp alteration | sericite alteration | muscovite alteration | muscovite alteration |
| No. of points counted | 1 050 | 1 200 | 1 050 | 1 188 | 1 200 | 750 | 1 200 | 750 | 1 200 | |
| **MINERAL** | | | | | | | | | | |
| | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* |
| Apatite | 0.4 | 0.1 | 0.2 | 0.4 | 0.5 | 0.2 | 0.8 | 0.3 | 0.3 | —— |
| Clinozoisite | 1.9 | 1.5 | 0.5 | —— | 0.1 | 0.1 | —— | 0.1 | —— | 0.5 |
| K-feldspar | 19.6 | 27.8 | 35.7 | 67.4 | 73.2 | 73.8 | 62.7 | 13.8 | 1.5 | —— |
| Albite | 34.0 | 17.3 | 33.2 | —— | —— | —— | —— | 0.3 | —— | —— |
| Anorthite | 8.5 | 6.7 | 8.0 | —— | —— | —— | —— | 0.1 | —— | —— |
| Muscovite | 0.7 | —— | 0.2 | 5.6 | 20.6 | 19.7 | 36.2 | 61.5 | 86.4 | 97.0 |
| Biotite | 7.5 | 4.9 | 5.3 | —— | —— | —— | —— | —— | —— | —— |
| Pyrite | 0.3 | —— | 0.2 | 0.4 | 0.6 | 0.1 | 0.1 | 2.3 | 0.2 | 2.5 |
| Quartz | 26.9 | 31.6 | 16.7 | 26.0 | 5.0 | 6.1 | —— | 21.6 | 11.5 | —— |
| Sphene | —— | —— | —— | —— | —— | —— | 0.1 | —— | —— | —— |
| Calcite | 0.2 | 0.1 | —— | 0.2 | —— | —— | 0.1 | —— | 0.1 | —— |
| | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |

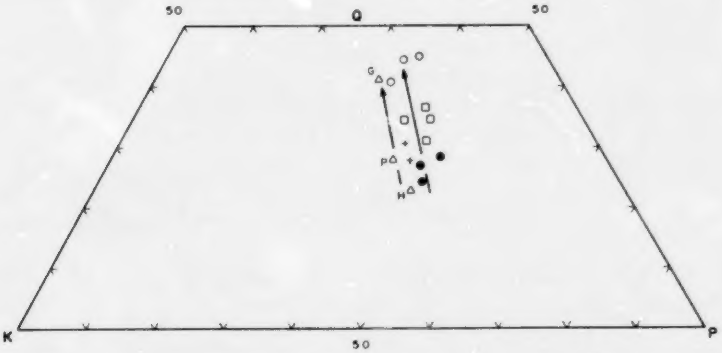

Figure 104. Mineralogical variations of principal rock units in the Oliver Plutonic Complex. Two trends are shown. Lettered triangles are averages of seven samples for each of the three principal rock types: H = hornblende-biotite quartz monzonite; P = porphyritic quartz monzonite; and G = garnet-muscovite quartz monzonite. This trend is compared with individual modes of specimens studied by Richards (1969).

Quartz veins containing small amounts of sulphides and precious metals are found in the Oliver pluton and surrounding rocks. Within the pluton large veins with some indicated economic potential are confined to the porphyritic quartz-monzonite phase. Quartz veins are cut by lamprophyre dykes that are highly variable in width and occur through the region. The largest known lamprophyre body is a near-vertical sheet about 15 metres (50 feet) wide that extends from Gypo mine southward for several thousand metres.

In the northern part of the area on Figure 103 are two large masses of medium to coarse-grained gneissic diorite consisting almost entirely of hornblende and plagioclase in variable proportions. These bodies resemble amphibolitic units of Vaseaux Formation to the north and probably represent large, partially assimilated masses of Vaseaux rocks.

The area has been faulted and fractured extensively. Contacts of the three main phases of the pluton have apparent offsets of 0.40 kilometre (one-quarter mile) or more, especially in the southern part of the area of Figure 103. Most of the region has been affected by hydrothermal alteration. In the northern part of the area where calcium-bearing minerals are most abundant the dominant alteration product is epidote which occurs in seams up to 2.5 centimetres (1 inch) in thickness. In the southern part of the region biotite is

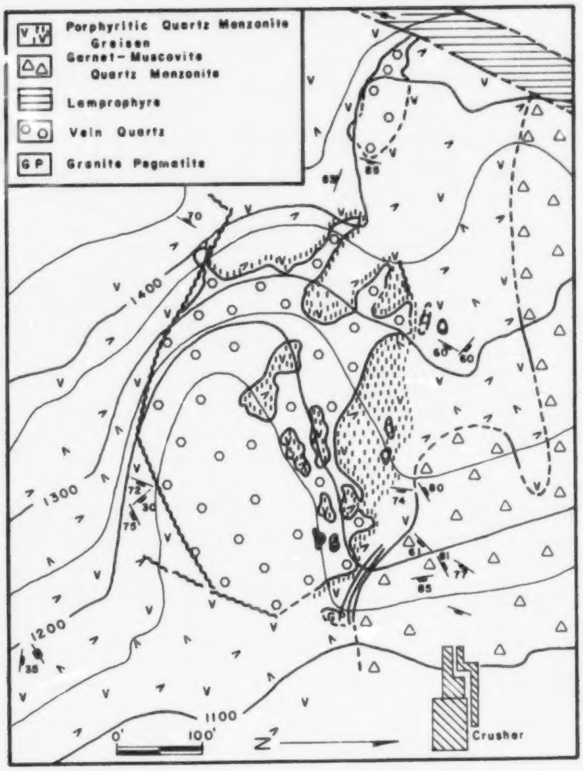

Figure 105. Detailed geology of the Gypo quarry and adjacent area.

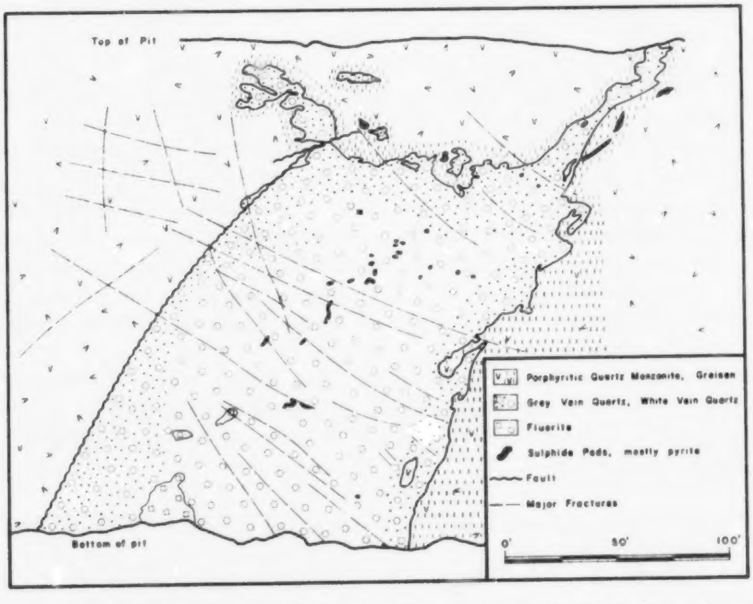
Top of Pit
Bottom of pit
Porphyritic Quartz Monzonite, Greisen
Grey Vein Quartz, White Vein Quartz
Fluorite
Sulphide Pods, mostly pyrite
Fault
Major Fractures
0'
50'
100'

Figure 106. Projection of near-vertical quarry face onto a vertical N–S section essentially perpendicular to the strike of the vein.

the abundant mafic mineral and chlorite is the most obvious result of regional hydrothermal alteration. Whether or not the region has been subjected to more than one period of hydrothermal alteration is not known. However, some of the alteration postdated emplacement of lamprophyre dykes and the development of some faults. Many fault zones appear to be later than alteration effects. The eastern edge of the area under consideration forms the western wall of the Okanagan Valley; it has been affected by extensive faulting and close-spaced fracturing. These features have not been studied in detail here but they are one of the latest tectonic events in the area and one might speculate that they are related to the development of the Okanagan Valley, which further north has been shown to be the locus of intense faulting of regional extent (*see* Little, 1961).

## GENERAL FEATURES OF VEIN DEPOSITS IN OLIVER PLUTONIC COMPLEX

Numerous quartz veins occur within the Oliver Plutonic Complex all of which show a number of features in common. In addition, a few relatively large quartz veins are known in Kobau metasedimentary rocks, such as the Morning Star and Stemwinder deposits of Fairview Camp that were mined several decades ago for their gold contents. The following general account applies only to those veins within the Oliver Plutonic Complex, some of which are shown on Figure 103.

In general, all veins within the Oliver pluton are characterized by an abundance of quartz, almost to the exclusion of other minerals. Pyrite is, perhaps, the only other mineral common to all veins but in many cases can be observed only with close inspection; it forms a negligible proportion of vein material in terms of total volume. Other minerals have been recognized locally, including gold and silver tellurides, galena, sphalerite, and native gold at the Standard deposit. It is occurrences such as the Standard vein that have prompted the limited exploration conducted in the area. Recent high precious-metal prices have resulted in short-term re-opening or re-investigations of the Susie and Standard mines.

Quartz in all deposits has been subjected to varying amounts of post-mineralization fracturing, commonly to the extent that original textures are in large part destroyed. However, where relatively undeformed, all deposits show evidence that much of the quartz was deposited as fairly large crystals, generally 2.5 centimetres (1 inch) or more in cross-section and at least several centimetres in length. In places these crystals show a rough cockscomb texture. All deposits contain at least some early deposited grey quartz although the bulk of the quartz is generally white. Wallrock alteration is not normally a pronounced feature of most of these deposits but all veins show at least a thin zone of sericitization along their margins. Large veins are restricted to the porphyritic quartz monzonite although smaller veins up to a few centimetres in width are found in both the core phase and the southern marginal phase. All quartz veins show some evidence of wallrock replacement but in most cases it is clear that the depositional process has been principally one of open-space filling. Most veins are very small, about 0.3 metre (1 foot) or less in width and extend laterally for distances of a few metres up to 30 metres (100 feet) or so. The so-called large veins are variable in thickness, commonly from 0.6 metre (2 feet) to 3 metres (10 feet) or more with strike lengths of several hundred to a thousand feet (300 metres) or so. Veins are mostly moderately to steeply dipping with variable strike direction.

In general, the similarity of features of quartz veins associated with the Oliver Plutonic Complex suggest that they have had a common origin that is somehow related to the pluton itself. Many of the features referred to are shown by the Gypo deposit, but on a much more grand scale than is general throughout the area.

## DETAILED GEOLOGY OF GYPO VEIN

Gypo deposit is a large quartz vein in porphyritic quartz monzonite near the contact with the core phase (Fig. 103). The deposit strikes east-west with a southerly dip of 55 to 60 degrees (Figs. 105 and 106). It is approximately 45 metres (150 feet) in true thickness at the quarry site and has a known strike length of about 150 metres (500 feet). A thinner extension from the main vein continues at least another 90 metres (300 feet) to the west. On the hangingwall (south) side the deposit is bounded by a thin shear zone 5 to 7 centimetres (2 to 3 inches) wide, occupied by gouge. At the west end of this fault apparent offset is small as is shown by continuity of protrusions from the vein on either side of the fault. The movement picture is not at all clear near the quarry entrance. Character of the footwall is in sharp contrast to that of the hangingwall zone. The footwall has been altered intensely for distances up to 30 metres (100 feet) from the vein, forming a greisen consisting predominantly of muscovite with lesser amounts of quartz. Furthermore, abundant relict patches of partially greisenized wallrock occur within the vein near the footwall.

The deposit has been cut by a near-vertical lamprophyre dyke that strikes roughly north-south near the western exposures of the quartz vein. Lamprophyres are common in the general area but this particular dyke is the largest yet found, with a width of about 15 metres (50 feet) and a strike length in excess of 700 metres (2,000 feet). The dyke contains about 45 per cent ferromagnesian minerals (olivine, augite, and biotite) in a K-feldspar matrix (35 per cent) with lesser amounts of apatite, plagioclase, and magnetite. Heat from this intrusion metamorphosed small pods of pyrite in the quartz vein, transforming them to pyrrhotite.

## MINERALOGY

**QUARTZ:** Three stages of quartz mineralization are recognized in Gypo deposit. Early (Stage I) quartz is grey in colour and is confined to country rock, alteration zones, and marginal parts of the vein. It is massive in character and the colour fades gradually over a distance of a few metres from the vein wall where it gives way to white quartz (Stage II) that makes up more than 95 per cent of the vein material. An explanation for the colour difference between these two types of quartz has not been sought in detail at Gypo deposit. Holtby (personal communications, 1972) did a trace-element study of white and grey quartz from the nearby Susie deposit and found there that grey quartz had a much higher manganese content than did white quartz. Distributions of the two types are shown on Figure 106.

The white quartz at Gypo deposit is principally in the form of giant crystals up to 0.3 metre to 0.6 metre (1 to 2 feet) in diameter and 2 metres (6 feet) in length (*see* Matson, 1959), hence the deposit qualifies as a quartz pegmatite. These crystals are observed intact only rarely, in part because most have been mined, but principally because the deposit has been fractured intensively with the production of numerous closely spaced smooth joint surfaces. These joints have given rise to the local name 'cleavage quartz' and commonly exhibit a rhombohedral form. We have examined this rhombohedral joint pattern in crystals at the quarry and others now used as decorative pieces in gardens in Oliver. In many cases, the joints parallel rhombohedral crystal faces but this is not the case everywhere. In some crystals as many as six fracture directions are apparent and invariably some of these joints, although not necessarily the best developed, are parallel to rhombohedral crystal faces. Some smooth joints can be traced from vein quartz into adjacent wallrock. Etch tests with hydrofluoric acid suggest the quartz was deposited as the low temperature polymorph.

Small amounts of quartz (Stage III) occur as thin delicate boxworks that cut earlier minerals, especially fluorite.

**FLUORITE:** Apple-green fluorite occurs in a series of irregular pods up to 2 metres (6 feet) or more in average diameter, distributed sporadically along a zone that is of more or less uniform distance from the hangingwall (*see* Fig. 106). The fluorite is intensively fractured and even fresh-looking specimens are extremely friable.

**MUSCOVITE:** Muscovite occurs in two distinct sizes. It forms very coarse-grained books up to 2.5 centimetres (1 inch) in diameter that occur intermixed with vein quartz near the footwall but medium-grained, massive muscovite that is characteristic of altered wallrock is much more abundant.

**SULPHIDES:** Sulphides form less than 1 per cent of the vein material. They are concentrated in small pods up to a few centimetres in diameter restricted to a thin zone in the central part of the vein (see Fig. 106). Pyrite is the principal sulphide but it has been metamorphosed to pyrrhotite adjacent to a lamprophyre dyke in the western part of the vein. Small amounts of chalcopyrite and molybdenite have been observed in polished sections. Minor amounts of marcasite are present as an alteration of pyrrhotite. Sulphide pods stand out clearly because all are limonitized and contrast sharply with white quartz on the quarry face. Small cubes of pyrite are a minor but ubiquitous component of altered country rock.

**APATITE:** Small amounts of apatite have been recognized in thin sections of altered rock, both greissen and feldspathized rock, in the footwall zone. The mineral has not been seen megascopically.

**CALCITE:** Small amounts of white to colourless calcite occur as thin veinlets and seams in quartz and locally forms small drusy cavities.

**MANGANESE STAIN:** Black stains, commonly with well-developed dendritic pattern are present on some crystal faces, on joints in quartz and wallrock, and as earthy material in weathered wallrock. These minerals have not been studied in detail.

## MINERAL ZONATION AND PARAGENESIS

A well-defined zonation of mineral varieties occurs within Gypo vein as illustrated on Figure 106. A relatively thin marginal grey quartz zone grades into white quartz occupying the interior of the vein. Regularly distributed within the white quartz are two separate zones, one characterized by large irregular pods of fluorite fairly close to the hangingwall and a second consisting of small sulphide pods more or less centrally located in the vein. Small grey quartz veins up to 0.30 metre (1 foot) in thickness are common around the margin of the main vein. These veins are cut by thin seams of muscovite whereas white quartz is not. The implied age relationship is consistent with order of deposition in the main vein. Position of fluorite and sulphides in the paragenetic sequence is less certain. Sulphides are centrally located in small cavities that indicate they were probably one of the last effects of hypogene mineralization. Fluorite distribution pattern suggests that it was deposited for a relatively short period within the interval of white quartz deposition. The Stage III quartz that cuts fluorite might simply be a continuation of Stage II quartz.

## WALLROCK ALTERATION

**FIELD ASPECTS:** Wallrock alteration has been extensive about the Gypo quartz vein, particularly along the footwall side (Fig. 106). The host, porphyritic quartz monzonite, has been altered almost completely to a friable mass of muscovite with minor amounts of grey quartz and, in places, a few relict 'horses' of host. In detail, these 'horses' are also altered by feldspathization upon which has been superimposed intensive muscovite alteration. The resulting alteration product is akin to a greisen, although some common greisen minerals such as topaz and cassiterite have not been recognized. This extensively altered zone grades rather abruptly into wallrock that is only slightly altered. It was collapse of this greisenized footwall zone in August 1968 that piled debris on the quarry floor and resulted in shutdown of mining operations. Field relations indicate that 'greisenization' occurred prior to extensive quartz deposition. The greisen is cut locally by early grey quartz veinlets up to a few centimetres wide and with sharp contacts. In places, however, such as the quarry entrance, thin replacement seams of muscovite extend through grey quartz and feldspathized zones. One of the striking features of the alteration is its apparent asymmetry – no extensive greisen zone occurs on the hangingwall (south) side of the vein. Further attention will be directed to this peculiarity in a later section.

Useful insight into the alteration processes can be had by investigation of small well-defined alteration envelopes about thin grey quartz veins adjacent to the main vein. Such an example is shown diagrammatically on Figure 107, a tracing of a photograph taken on the south side of the quarry entrance. Here, relatively flat-lying quartz veins, each a few centimetres to 0.30 metre (1 foot) in thickness, contain on their lower side a massive muscovite zone. The combined quartz and muscovite zones are surrounded by a pink alteration envelope consisting predominantly of K-feldspar and having a thickness comparable to that of the quartz vein. This alteration zone grades fairly abruptly into relatively unaffected wallrock. In places one finds thin seams of muscovite a fraction of a centimetre thick that cut the K-feldspathized zone. These seams are products of metasomatism that extend into otherwise unaltered wallrock and apparently are fracture-controlled. This relationship establishes relative ages of alteration types-K-feldspathization followed by greisenization. A similar age relation can be seen in the large intensity greisenized footwall zone where feldspathized masses of wallrock have been replaced irregularly by greisen.

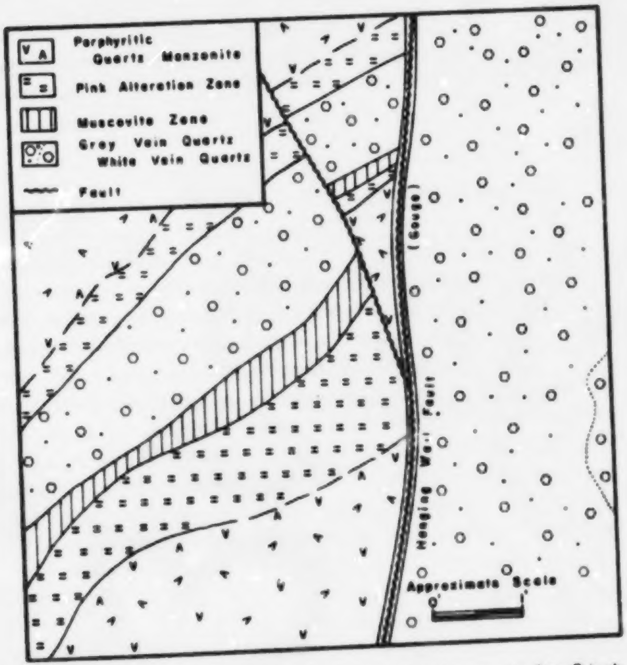

Figure 107. Details of mineralogical zoning in and around a 4 to 6-inch-wide grey quartz vein at the margin of and in fault contact with the main vein. South side of quarry entrance.

**PETROGRAPHY:** Modal analyses of unaltered wallrock and the two extreme types of alteration, based on approximately 1 100 points per thin section, are listed in Table 2. Mineralogically the two types of alteration are distinct. One is predominantly K-feldspar (at least two-thirds by volume) with much smaller and variable amounts of muscovite and quartz. The other, greisen, is almost exclusively muscovite with small amounts of quartz. Pyrite occurs as an accessory mineral in both types and appears somewhat more abundant in the greisen than in the K-feldspar alteration.

In general, alteration products are medium-grained and massive and, with their distinctive mineralogies are easily recognizable in the field. As mentioned earlier, typical accessory minerals in greisen such as topaz and cassiterite have not been identified although fluorite is a minor constituent, as are apatite and molybdenite.

**EXCHANGE OF ELEMENTS DURING ALTERATION:** Wallrock alteration has been effected by extensive metasomatism involving the complete making over of original country rock. Although this probably took place principally within solid rock, there is some indication that open-space filling played a significant part in the process of greisenization. For example, on the hangingwall (south) side of the vein, small seams of muscovite (identical with large massive patches of greisen) have formed by replacement of fracture walls. Similarly, on the footwall (north) side, within the zone of intense greisenization veinlets of medium-grained muscovite cut relict patches of feldspathized wallrock.

The investigation of element transfer during metasomatic processes presents problems because of the uncertainty as to what might represent a standard feature of reference that remained unchanged during metasomatism. Various underlying assumptions have been made as a standard for calculations, including: constant volume (Lindgren, 1918), constant cation percentages (Barth, 1952), constant oxygen atoms (Barth, 1952), and constant silica tetrahedra (Poldervaart, 1953). Calculation of element exchange, using all the foregoing assumptions, requires chemical analyses that were not available to us. However, it is possible to calculate chemical compositions approximately from detailed modal analyses, providing that chemical compositions of constituent minerals are known fairly precisely. We had tested this approach previously by comparing such calculated chemical compositions with actual chemical analyses for specimens from the Copper Mountain area (Montgomery, 1967) and found surprisingly close agreement between the two methods. Consequently, we proceeded to calculate chemical compositons for unaltered rock, K-feldspathized samples, greisen samples, and several transitional rocks using a computer program patterned after that of Dietrich and Sheehan (1964). Calculations are based on average mineral compositions for rocks of similar geological settings taken from Rankama and Sahama (1950).

Using the calculated chemical compositions as a base, we then proceeded to investigate the four methods mentioned earlier for examining exchange of major elements during metasomatism. Qualitatively, all methods showed essentially similar trends for individual elements but quantitavely they differ somewhat one from another. For purposes of presenting the results, we use the method of Barth (1952) based on an assumption of constant numbers of oxygen atoms during metasomatism of silicate rocks. Results are shown on Figure 108 and are summarized briefly below.

The most pronounced chemical changes resulting from metasomatism are shown on Figure 108a and involve obvious decreases in silicon and sodium and increases in aluminum, hydrogen, and potassium, all by a factor of about two or more. These chemical variations are apparent whatever method is used to estimate chemical exchange, and whether average or ideal mineral compositions are used in estimating the chemical composition from modal analyses.

Chemical variations of the less abundant elements are shown on Figure 108b. Because of low abundances, estimated amounts of these elements are more susceptible to variation depending on the particular mineral compositions used in calculations. Nonetheless, the trends shown are consistent regardless of the standard reference state chosen for metasomatism. Of this group only calcium decreases consistently. Other elements such as iron, magnesium, and sulphur appear to decrease in the initial stage of alteration and then increase during greisenization. Iron is of particular interest – it is present mainly in biotite (and chlorite) in unaltered rock, is drastically reduced in the feldspathized zone which is almost devoid of mafic minerals, and then increases drastically in the greisen zone due to its fixation with sulphur as pyrite. Other elements, such as phosphorus, titanium, manganese, and carbon (or $CO_2$) show no particular change, although this could be more apparent than real because of their low abundance and the relatively low accuracy in making estimations.

On the average, unaltered wallrock contains 234 silica tetrahedra per cubic centimetre as compared with 175 silica tetrahedra per cubic centimetre of greisen. Assuming no loss of silica tetrahedra, the tetrahedra originally distributed through 1 cubic centimetre of unaltered wallrock now must be distributed in 1.42

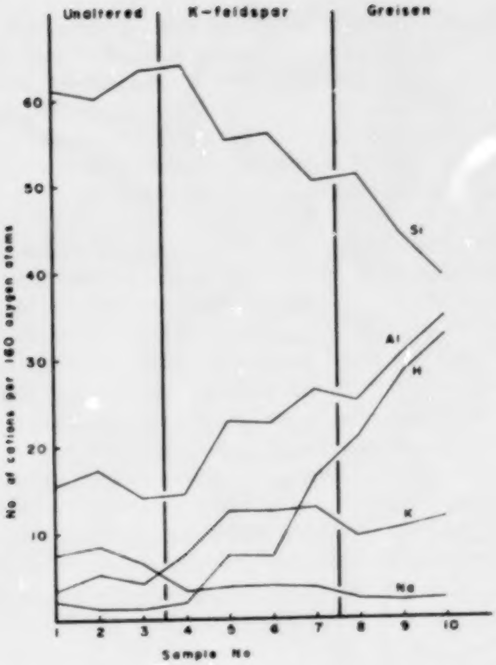

Figure 108a. Graph showing relative exchange of major elements during metasomatism, using Barth's standard cell of 160 oxygen atoms as a reference.

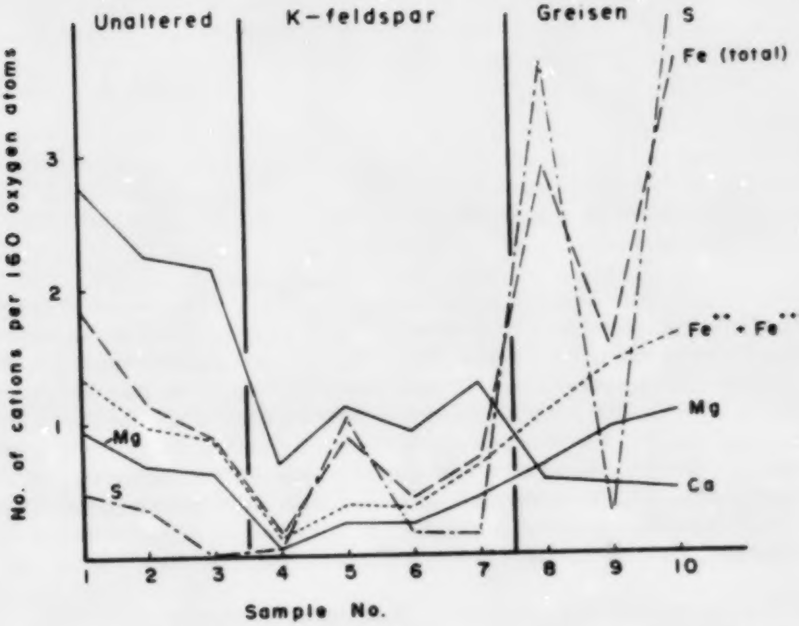

Figure 108b. Graph showing probable relative exchange of some minor elements during metasomatic wallrock alteration, using Barth's standard cell of 160 oxygen atoms as a reference.

cubic centimetres of altered rock, implying a volume increase of about 34 per cent. Although one cannot attach significance to the precise figure, the major conclusion to be derived from this calculation based on the assumption of constant numbers of silica tetrahedra is that a substantial increase in volume has occurred as a result of metasomatic changes. Ames (1961) has suggested that replacement in a closed system involving an increase in volume will continue until all voids in the rock undergoing replacement are filled. This process seems to provide an adequate explanation for thin greisen seams that have developed along joints at Gypo deposit. In general, however, it appears unlikely that metasomatism occurred entirely, if at all appreciably, in a closed system. The indicated volume change, for example, requires a considerable open space into which the altered rock could expand. Whatever the fundamental nature of the processes producing this space (that is, fracturing or chemical dissolution) an open system is implied. Fracturing, for example, suggests through-going channel ways, as does complete removal by chemical dissolution. The argument of an initially open system is further supported by mass balance calculations which show that $SiO_2$ released during alteration could account for only about 20 per cent of quartz now existing in the vein (Moore, 1970). Consequently, one must assume that the remaining 80 per cent of quartz in the vein is truly epigenetic and was introduced in the form of dilute aqueous solutions. The tremendous quantity of solutions that would have been required preclude a closed system.

Greisen veinlets and masses commonly show sharp contacts with quartz and, in fact, cross-cutting relations prove that some greisen formed later than some of the grey quartz. On the other hand, greisen is intermixed intimately with grey quartz. No such relations exist between greisen and white quartz. It seems probable that greisenization preceded white quartz deposition but was contemporaneous with at least the early part of grey quartz deposition.

However, textural data suggest that a small proportion of the muscovite, in particular the very coarse-grained variety, precipitated from the same solutions from which quartz was deposited. In small flat-lying veins the result is akin to that produced by crystal settling, producing an asymmetry of the muscovite zone. Such an origin might account, in part, for the asymmetry observed in the main vein.

## SPACE PROBLEM

Both open-space filling and replacement processes were operative in the development of Gypo deposit. The extensive footwall greisen zone provides ample evidence of replacement, whereas the presence of giant quartz crystals whose termination point towards the centre of the vein suggests a dominant role of open-space filling. Both processes seem to require an open system. These conclusions lead to a problem in explaining how space was produced for the development of the vein. Mass balance calculations indicate that a maximum of about one-fifth of the total vein volume could have been produced by quartz formed as a result of metasomatism of wallrock. The remainder of the volume must be accounted for by the presence of pre-existing open spaces.

The problem has not been solved as a result of field and laboratory work and one is led to speculate on possible mechanisms. The peculiar shape of the vein in cross-section, that of a tilted rectangular block with upward extensions from each of the top two corners, suggests a plausible means of developing openings. The writers suggest that a centre of intensive fracturing existed at the site of the present vein, leading to extensive alteration. Rock thus weakened, foundered with continuing tectonic activity to produce a large opening in which quartz deposition continued. This hypothesis has the advantage that it provides an explanation for the unusually great width of the vein in the area of the quarry, as well as for the thin vein extensions both upward and to the west. However, it requires that the vein bottoms at some unknown depth, down dip at the top of the foundered block(s). This hypothesis also provides an explanation for asymmetry of the greisen zone (compare Fig. 107), that is, the 'missing' greisen zone on the hangingwall side (vestiges of which are present as discussed in the section on field aspects of alteration) is part of the foundered block.

## RADIOMETRIC DATING

Unpublished rubidium-strontium isotopic dating of the Oliver Plutonic Complex provides an age of emplacement at about 160 Ma, that is, mid-Jurassic (R. L. Armstrong, personal communication, 1981). Potassium-argon ages summarized in Table 3 are all substantially lower than the rubidium-strontium date. Muscovite potassium-argon data for the garnet-muscovite quartz monzonite and the Gypo greisen zone group at about 140 Ma suggesting either a thermal event at that time or a high heat flow from 160 Ma to 140 Ma. Biotite ages are much less, perhaps due to variable local resetting during the Tertiary thermal event represented by the biotite-augite lamprophyre dated at 52 Ma.

### TABLE 3
### POTASSIUM/ARGON MODEL AGES FOR IGNEOUS ROCKS AND WALLROCK ALTERATION NEAR OLIVER

(After White, *et al.*, 1968, with additions)

| UBC NO. | UNIT | ROCK TYPE | AGE (Ma)* | |
|---|---|---|---|---|
| W65-1 | Kruger syenite | Quartz monzonite (Horn Silver mine) | Pyroxene-hornblende | 152±8 |
| W65-2 | Fairview granodiorite | Granodiorite | Biotite | 111±5 |
| W65-3 | Oliver Plutonic Complex | Hornblende-biotite quartz monzonite | Biotite | 118±4 |
| W65-4 | Oliver Plutonic Complex | Porphyritic quartz monzonite | Biotite | 82±3 |
| W65-5 | Oliver Plutonic Complex | Porphyritic quartz monzonite | Biotite | 103±4 |
| W65-6 | Oliver Plutonic Complex | Garnet-muscovite quartz monzonite | Muscovite | 139±5 |
| W65-7 | Gypo, footwall greisen zone | Muscovite-quartz alteration | Muscovite | 140±6 |
| W66-2 | Mafic dyke, Gypo deposit | Biotite-augite lamprophyre | Biotite | 53±2 |
| W66-5 | Oliver Plutonic Complex | Garnet-muscovite quartz monzonite | Muscovite | 144±6 |
| W67-1 | Susie, wallrock alteration | Sericitized porphyritic quartz monzonite | Sericite | 114±5 |
| W67-2 | Standard, wallrock alteration | Sericitized porphyritic quartz monzonite | Sericite | 117±5 |

*Error is laboratory reproducibility (one standard deviation).

## CONCLUSIONS

Gypo quartz vein developed in the porphyritic quartz monzonite phase of the Oliver Plutonic Complex about 160 Ma ago, shortly after consolidation of the host. A genetic relationship almost certainly exists between Oliver Plutonic Complex, Gypo quartz veins, and other smaller nearby quartz veins. At Gypo, wallrock replacement has been fairly extensive but the bulk of the vein quartz must have been deposited from hydrothermal solutions in an open system. Origin of the opening in which Gypo vein developed is uncertain but might have formed by foundering of a large fault-bounded block of partly greisenized country rock.

At an early stage in development of the vein the adjacent country rock was extensively feldspathized, probably contemporaneously with deposition of early grey quartz. Small grey quartz veinlets in the surrounding rock formed at the same time. Concurrent with continued deposition of grey quartz and some muscovite, there was a period of intensive greisenization. Foundering of a weakened central block of country rock might have occurred principally at this time or perhaps somewhat earlier to provide a large open space in which white quartz was deposited. Fluorite was precipitated during a short interval within the period of white quartz deposition. Small pods of sulphide located centrally in the vein were the last hypogene mineralization. The calcite might, in part, be the result of late-stage hypogene mineralization, but it has a regional occurrence and is probably largely due to a later superimposed regional hydrothermal alteration. This could, in part, have been related in time to a period of Early Tertiary lamprophyre dyke emplacement but is also, in part, younger. Lamprophyre dykes metamorphosed nearby pyrite to pyrrhotite.

Fracturing affected the deposit and the area several times after vein formation. One period of fractures predates and another postdates regional hydrothermal alteration. The abundant major faults and joint systems that cut rocks in and near the vein are probably related to a Late Tertiary tectonic event that produced much of the fracturing apparent in the Okanagan Valley and caused the development of so-called 'cleavage' in Gypo quartz.

Later mineralizing effects include deposition of black manganese stain in and near the vein, alteration of pyrrhotite to marcasite, and the production of limonite from both pyrite and pyrrhotite.

## ACKNOWLEDGMENTS

R. Nethery and J.F.W. Orr assisted with the detailed plane table mapping of Gypo vein. The assistance and cooperation of Mr. Ivan Hunter, former Manager of Pacific Silica Company, Oliver, British Columbia is greatly appreciated. A. Bentzen provided technical assistance at various stages through the study. This project was supported, in part, by funds from the National Science and Engineering Research Council of Canada.

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# PRELIMINARY REPORT ON WALLROCK ALTERATION ERICKSON GOLD MINE, CASSIAR DISTRICT

## (104P)

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## INTRODUCTION

The Erickson Gold mine is 12 kilometres southeast of Cassiar, British Columbia (104P/4). Production commenced in April 1979 and presently averages 170 tonnes per day grading approximately 17.0 grams gold per tonne and 15.0 grams silver per tonne.

Mineralization is in quartz and carbonate veins contained in intermediate to mafic volcanic rocks, chert, argillite, ultramafic, and exhalative sedimentary rocks of the Sylvester Group. Where the veins are in contact with volcanic rocks, graphite and/or carbonate alteration envelopes generally are well developed. This paper describes the megascopic characteristics of zoning and differences within the alteration envelopes.

An idealized model of the vein-alteration halo is illustrated on Figure 109. Veins commonly range up to 5 metres in thickness and associated alteration haloes extend from near 0 to 40 metres, although 1 to 15 metres is common where volcanic material forms the host.

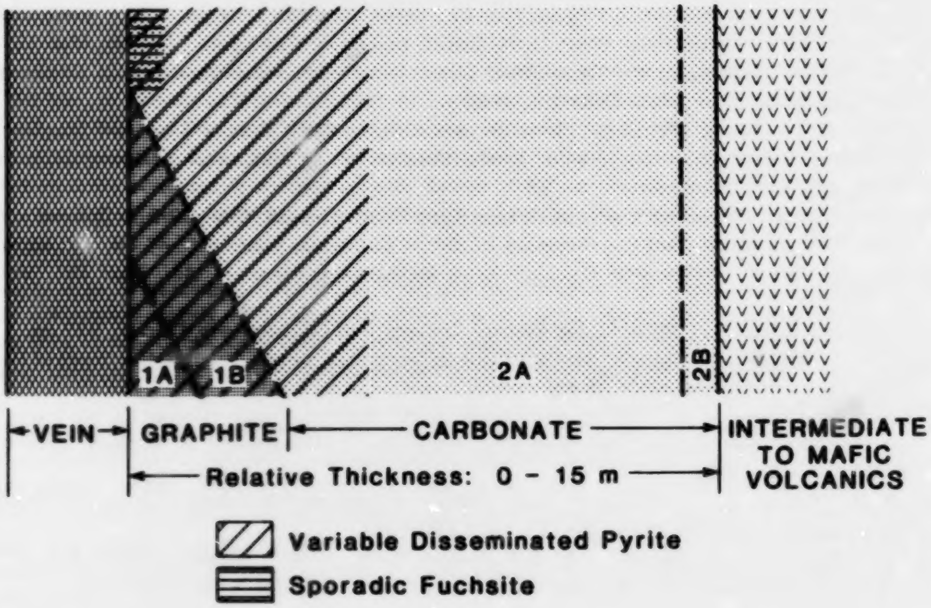
1A
1B
2A
2B
VEIN
GRAPHITE
CARBONATE
INTERMEDIATE TO MAFIC VOLCANICS
Relative Thickness: 0 - 15 m
Variable Disseminated Pyrite
Sporadic Fuchsite

Figure 109. Cross-section of idealized alteration halo characteristic of quartz and carbonate veins, Erickson Gold mine, Cassiar.

The entire alteration halo generally is divisable into several zones. The most clear-cut change is from an outer carbonate zone (2) gradationally into an inner graphite-bearing zone (1) adjacent to the vein. Each of these zones can be further subdivided. In the following section general descriptions are presented of the character of unaltered wallrock and the individual alteration zones. These start with the 'unaltered' wallrock and continue with zones inward toward the vein. A summary of descriptive material is provided in the accompanying table.

**DESCRIPTION OF IDEAL ALTERATION ZONING
RELATED TO QUARTZ AND CARBONATE VEINS AT THE ERICKSON GOLD MINE**

| Zone | Thickness *metres* | Occurrence | Colour | Textures | Mineralogy |
|---|---|---|---|---|---|
| country rock intermediate to mafic volcanics | | host | medium to dark green | massive and pillowed flows, breccias, massive to layered tuffs ± crackled texture | plagioclase, actinolite, chlorite, epidote, calcite, quartz, Ti oxides ± pyrite |
| slight carbonate 2b | <1 | very common | pale green to tan | massive, aphanitic to fine-grained ± crackled texture | plagioclase, Ca-Fe-Mg carbonates, sericite, chlorite, epidote, quartz, Ti-oxides ± pyrite |
| moderate to intense carbonate 2a | <15 | very common | tan with minor purplish grey mottling | massive, aphanitic to fine grained ± crackled texture | Fe-Mg-Ca carbonates, sericite, fuchsite, quartz, Ti-oxides, plagioclase ± pyrite |
| slight to moderate graphite 1b | <4 | uncommon | tan to light and dark grey | massive, aphanitic to fine-grained ± crackled texture | Fe-Mg-Ca carbonates, graphite, sericite, quartz, Ti-oxides ± pyrite |
| intense graphite 1a | <2 | uncommon | black | massive, soft, friable, fine-grained, frequently crosscut by slickensides, occasional fine porosity | graphite, Fe-Mg-Ca carbonates, quartz ± pyrite |
| vein | <5 | very common | white to tan ± black bends | massive to layered with stylolites | quartz ± Fe-Mg-Ca carbonates, graphite, sulphides, gold, altered wallrock fragments |

**VOLCANIC COUNTRY ROCK:** Country rocks are volcanic rocks of andesitic to basaltic composition that typically are medium to dark green and weather to a dark green to black. Most exposures consist of aphanitic to fine-grained massive rocks that commonly contain well-developed pillows. Less commonly breccias and well-laminated tuffs are observed. A cross-cutting network of dark green to black hairline fractures may be present imparting a 'crackle' texture to the rocks. Constituent minerals of the 'unaltered' wallrock include plagioclase, actinolite, chlorite, epidote, calcite, quartz, and titanium-oxides. Disseminated, fine to coarse-grained pyrite may be present also.

**ALTERATION ZONE 2B:** Zone 2B marks the transition from country rock to carbonate altered rock; it is typically pale green to buff and may have a speckled or mottled texture. Most of the altered volcanic rocks are massive and aphanitic to fine grained, although in places primary textures may be visible. A 'crackled' texture, evident because of dark green to black hairline fractures, may be superimposed on the rock. Mineralogically the zone is characterized by partial alteration of plagioclase to iron-magnesium-calcium carbonates and sericite. Chlorite, epidote, quartz, titantium-oxides, and pyrite may also be present in lesser amounts. The width of the transition zone is generally less than one metre, but may be much wider, especially if abundant stringer veins are present. The zone is almost invariably present adjacent to both quartz and carbonate veins.

**ALTERATION ZONE 2A:** In Zone 2A there is moderate to intense carbonate alteration of the volcanic rocks near the veins; it is most commonly buff coloured, massive, and aphanitic to fine grained. Locally, varying shades of purplish-grey impart a mottled texture to the rock. A crackled texture of black hairline fractures may be present locally. Constituent minerals include varying amounts of iron-magnesium-calcium carbonates, sericite, fuchsite (chromian muscovite), quartz, titanium-oxides, and plagioclase. The fuchsite occurs as sporadic blebs less than 1 centimetre in diameter. These blebs are found in that part of the zone closest to veins, but only where the zone is in contact with the vein. Coarse euhedral pyrite crystals may also occur in the portion of the zone closest to veins, even if the zone is not in direct contact with the vein. Zone 2A is normally less than 15 metres wide and is commonly present; it occurs adjacent to both quartz and carbonate veins.

**ALTERATION ZONE 1B:** Zone 1B marks the transition from carbonate to graphite-altered rock. The transition is gradational; colour changes from buff to pale or dark grey; the texture is massive and aphanitic to fine grained. Ordinarily, black hairline fractures crosscut the rock. Mineralogically the zones are characterized by variable amounts of graphite with iron-magnesium-calcium carbonates, sericite, quartz, and titanium-oxides. Coarse euhedral pyrite crystals may be scattered throughout the zone or concentrated closer to the veins. Zone 1B is not present in all alteration haloes but where formed it is typically less than 4 metres wide. This zone may occur without an adjacent zone of intense carbonate alteration, but such occurrences are rare.

**ALTERATION ZONE 1A:** Zone 1A is marked by intense graphite alteration. The rock is typically fine grained, black, massive, soft and friable. It is prominently slickensided and may have a fine porous texture. Mineralogically graphite dominates; there are lesser iron-magnesium-calcium carbonates and quartz. Pyrite may also occur but in smaller amounts than in previously described zones. Zone 1A is uncommon; where present it is generally less than 2 metres wide.

**PYRITE:** Pyrite occurs in variable amounts in all alteration zones. Concentrations up to 5 per cent are noted adjacent to veins; pyrite decreases in size and amount away from the vein. Fine-grained pyrite predominates; the coarse-grained euhedral pyrite generally occurs within 1 metre of a vein. The euhedral pyrite crystals may attain a diameter of 5.0 millimetres.

## GENERAL COMMENTS

Most veins are composed almost entirely of quartz with minor amounts of scattered iron-magnesium-calcium carbonates. A few veins have graphite ribbons and stylolitic textures. Sulphide minerals in the veins are pyrite, tetrahedrite, chalcopyrite, and sphalerite; there are minor amounts of free gold. Graphite and carbonate altered wallrock fragments may be incorporated into veins. They also occur in localized contact breccia zones. Less commonly, layered carbonate veins, with only minor amounts of quartz, are observed. In the carbonate veins only pyrite occurs; it is concentrated along layers and occurs as disseminations. Only carbonate alteration is observed in country rock adjacent to such veins.

There are no systematic changes within alteration haloes throughout the mine; however, specific zones may be absent and zones vary widely in width from one vein to another. Carbonate alteration is typically present whereas graphite alteration, particularly the more intense type, is uncommon. Generally, alteration zones have quartz and/or carbonate veins in their cores; however, some do not. In general, alteration envelopes are relatively symmetrical but the thickness on the hangingwall side is up to twice that on the footwall side. Both hangingwall and footwall alteration thicknesses average from two to six times the vein thickness. Alteration envelopes rarely extend more than 40 metres from a vein; in most cases they extend less than 15 metres from the vein margin.

This report is a summary of preliminary fieldwork on megascopic characteristics of graphite-carbonate alteration zones developed in volcanic rocks at the Erickson Gold mine. The work is directed toward investigating wallrock alteration patterns. Future work will focus on mineralogical and elemental zoning patterns within the alteration zones.

## ACKNOWLEDGMENTS

This work was supported financially by Erickson Gold Mines, Ltd. who have kindly granted permission for publication.

# STATISTICAL EVALUATION OF DUPLICATE SAMPLES REGIONAL SEDIMENT SURVEYS, BRITISH COLUMBIA

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## INTRODUCTION

The ability to discriminate real trends related to geological and geochemical causes from those that result from spurious factors such as sampling and analytical errors is of paramount importance in the success of geochemical data interpretation. Since the estimate of reproducibility (precision) allows us to quantify the amount of variation due to sampling and laboratory analysis it is an integral part of the evaluation of geochemical data and should be conducted prior to carrying out any detailed interpretation.

As part of our continuing study of rapid but thorough evaluation procedures for multi-element stream-sediment data (for example, Matysek, *et al.*, 1981) we designed a systematic computer-oriented method of evaluating the quality of geochemical survey data based on field-site duplicates. It incorporates a bias test, an analysis of variance technique, and the Thompson and Howarth (1976) approach to quantifying precision.

This detailed procedure utilizes the type and quality of data incorporated in various regional geochemical programs undertaken by the British Columbia Ministry of Energy, Mines and Petroleum Resources (the Ministry), but can be adapted easily for other programs.

## GENERAL METHODOLOGY

In brief, our general approach to evaluation of the quality of geochemical data sets involves the following steps:

(1) Extraction of at least 50 independent, field-site duplicate pairs from a geochemical data set for use in subsequent data analysis.

(2) Determination of the degree of systematic bias between duplicate pairs based upon the number of cases in which the first observation is greater than the duplicate.

(3) Evaluation of the duplicated geochemical data set in terms of metal variability at the regional, between-sample site and at the local, within-sample site, sampling, and analytical levels by a two-factor analysis of variance technique.

(4) Quantification of the within-sample site variability by estimating precision utilizing the Thompson and Howarth (1976) method.

## DATA

Data obtained from the three most recent regional geochemical surveys undertaken by the Ministry (1981) were evaluated using this method. The base data consist of analyses of stream sediments and water samples collected at an average density of one sample per 17.3 square kilometres over NTS map-sheet areas 92H, 92I, and 92J. Silt samples were field dried and the minus 80-mesh (177 microns) fraction retained for subsequent analyses.

The samples were analyzed for zinc, copper, lead, nickel, cobalt, silver, manganese, iron, molybdenum, arsenic, and antimony by the atomic absorption method. Tungsten was determined colorimetrically, uranium in the water samples was determined by a fluorometric method, and fluoride in stream waters was determined using a specific ion electrode (Garrett, 1975).

Field-site duplicates were also collected to provide information on analytical precision over a range of concentrations and to give some impression of sample representivity or geologic variation. Altogether, 132 pairs of duplicate field-site samples were extracted from the data set. Individual duplicate samples were recorded as 'first' of field-site duplicate and 'second' of field-site duplicate in the publically available general information guide distributed by the Ministry. Duplicates were collected at a density of one per block of 20 samples. The location within the sample block was random so they could not be distinguished from other samples by the contracted commercial laboratory.

Sampling and analytical error associated with zinc, copper, nickel, cobalt, manganese, and iron distributions were investigated by this study. This particular suite of metals were selected for the following reasons:

(1) The majority of their reported analytical values exceeded their published detection limits.
(2) Their distributions exhibited a wide range of concentration values.

## BIAS TEST

A characteristic of numerical measurement is inconsistency in repeated measurements of the same quantity. Two types of error contribute to the unreliability of a measurement; random errors arising from the variations inherent to any sampling and measurement process, and non-random errors causing systematic negative or positive deviations from the true results. If these non-random systematic errors are significantly large, precision estimates determined by an analysis of variance or by the Howarth and Thompson method may be suspect, since they are meant to detect random error only.

A bias test was utilized to assess the degree of systematic non-random error between the determined metal contents of the first sample and its duplicate. The test is based upon the number of sample pairs in which concentration in the first sample is greater than that in the duplicate. If there is no bias this number (m) should be close to half the total number of (n) pairs and the frequency distribution of possible results should correspond with successive terms of the binomial expansion of:

$$[(1/2) + (1/2)]^n$$

The number of duplicate pairs exceeds 50, therefore, its frequency distribution approximates that of the normal distribution, having mean and a standard deviation of $n/2$ and $n/\sqrt{2}$ respectively. The observed incidence (m) is then converted into the standardized normal deviate. The probability of obtaining a result of (m) or greater can be obtained from the usual tables for the areas in the tails of the normal distribution.

## ANALYSIS OF VARIANCE

The second stage in our procedure is to evaluate the geochemical data set in terms of variability at regional (between-sample site) and local levels (within-sample site). Only if a significant proportion of the data variability is at the regional level can one be confident that differences in metal concentrations between-sample sites reflect a real trend related to geological and geochemical features, not merely a consequence of sampling and analytical error.

Significance of metal variability within-sample sites due to sampling and analytical errors versus dispersion between-sample sites can be determined by standard analysis of variance techniques. For our purposes, the significance of the various sources of variation can be determined from logarithmic values of duplicate samples using a two-factor analysis of variance. Theory and assumptions inherent in this method are described by Krumbein and Graybill (1965) and Koch and Link (1971). The formal design for the analysis of variance is given in Table 1.

TABLE 1. ANALYSIS OF VARIANCE

| SOURCE OF VARIATION | DEGREE OF FREEDOM | SUM OF SQUARES | MEAN SQUARE | F |
|---|---|---|---|---|
| Error (sampling, sub-sampling, analysis | $l-1$ | $m\sum_{i}(\bar{x}_i-\bar{x})^2$ | $S_1{}^2=\frac{m}{l-1}\sum_{i}(\bar{x}_i-\bar{x})^2$ | $F_1=S_1{}^2/S_3{}^2$ |
| Geochemical variation | $m-1$ | $l\sum_{j}(\bar{x}_j-\bar{x})^2$ | $S_2{}^2=\frac{1}{m-1}\sum_{j}(\bar{x}_j-\bar{x})^2$ | $F_2=S_2{}^2/S_3{}^2$ |
| Residual | $(l-1)(m-1)$ | $\sum_{i}\sum_{j}(\bar{x}_{ij}-\bar{x}_i-\bar{x}_j+\bar{x})^2$ | $S_3{}^2=\frac{1}{(l-1)(m-1)}\sum_{i}\sum_{j}(x_{ij}-\bar{x}_i-\bar{x}_j+\bar{x})^2$ | |
| Total | $N-1$ | $\sum_{i}\sum_{j}(\bar{x}_{ij}-\bar{x})^2$ | $S_4{}^2=\frac{1}{N-1}\sum_{i}\sum_{j}(x_{ij}-\bar{x})^2$ | |

$x_{ij}$ = result for the $i$th replicate from the $j$th site; $i = 1, 2, \ldots\ldots l$th result ($l$ is usually 2);
$j = 1, 2, \ldots\ldots m$th result; $N = lm$ = total number of results; $\bar{x}_i$ = mean of $i$th replicate group;
$\bar{x}_j$ = mean of $j$th site group; and $\bar{x}$ = overall mean.

The significance of metal variability between-sample sites (geochemical variation) and metal variability within-sample sites (sampling and analytical errors) is determined from the F-statistic. The value of F, which is significant, can be obtained from standard statistical tables; it is a function of the number of duplicates collected, the number of duplicates collected at each site, and the significance level selected for the investigation. Relative variance components have also been calculated as described by Garrett (1969, 1973) and correspond to the average percentage of variability explained by each source at a sample site.

## THOMPSON AND HOWARTH PRECISION METHOD

The final stage in our evaluation of the quality of geochemical data sets is to quantify the amount of variation due to sampling and analytical error. This variation can be expressed in terms of precision which, in geochemical practice, is specified as the per cent relative variation at the two standard deviation (95 per cent) confidence level:

$$Pc = 2\,Sc/C \cdot 100\% \quad (1)$$

where (Pc) is the precision in per cent at concentration (c) and (Sc) is an estimate of the analytical standard deviation (Oc) at that concentration.

Application of analysis of variation techniques can only determine an average precision value for a range of concentrations. In actual fact it has been shown (Thompson and Howarth, 1976) that where there is a wide range of concentrations in a set of samples, both the absolute and relative errors in analytical determinations can vary across the range. To overcome this failing, alternative methods of estimating precision using randomly selected duplicates have been considered by Thompson and Howarth (1973, 1976, 1978) and Howarth and Thompson (1976).

Briefly, their method involves dividing 50 or more duplicate samples into narrow concentration ranges and employing the medium of absolute differences between pairs of duplicate analyses ($X_1$, $X_2$) as an estimator of the standard deviation (Oc). The group mean value of all the mean average values $[(X_1 + X_2) / 2]$ is used as an estimator of the average concentration. If this procedure is repeated for a number of successive narrow concentration ranges a set of corresponding mean concentration and standard deviation estimates are obtained. The relationship between them can be found by simple linear regression. From the expression:

$$Sc = So + Kc \quad (2)$$

through substitution of (1) above Pc is given by:

$$Pc = 200\,(So/c + K) \quad (3)$$

where (So) is the standard deviation at zero concentration and (K) is a constant.

This linear function has been determined in many practical cases to be a satisfactory model for the expression of the variation. In our case, where duplicates were independent samples collected in the field and analysed once each, the method will assess the overall error, which includes both sampling and laboratory error.

The following rapid procedure is suggested for estimation of precision from a minimum of 50 pairs of duplicate samples (Thompson and Howarth, 1976):

(1) From the duplicate analyses obtain a list of the means and absolute difference.
(2) Arrange the list in increasing order of concentration means.
(3) From the first 11 results obtain the mean concentration and median difference from that group.
(4) Repeat step (3) for each successive group of 11 results, ignoring any remainder less than 11.
(5) Calculate or obtain graphically the linear regression of the median differences on the means and multiply the intercept and coefficient by 1.048 to obtain (So) and (k), respectively.

In order to assess the significance of the precision parameters obtained from the linear regression, the calculated slope and intercept were individually evaluated by a t-test. Significance of the resulting regression was also determined by an analysis of variance.

## RESULTS

Table 2 illustrates the results obtained from the bias test. From this table we observe:

(1) Incidence of positive difference in metal content between duplicate pairs is greater than the number of negative differences for each of the metals analysed.

(2) Metals nickel, cobalt, copper, and manganese exhibit appreciable, but minor, systematic bias.

(3) A significant systematic bias for metals zinc and iron is indicated by the extremely low probability ($<1$ per cent) of obtaining such a high proportion of positive differences in metal contents between duplicate pairs.

(4) The number of duplicate pairs exhibiting identical metal concentrations averages greater than 1 in 4.

TABLE 2. TEST FOR SYSTEMATIC BIAS

| METAL | NO DIFFERENCES *No. (per cent)* | POSITIVE DIFFERENCES | NEGATIVE DIFFERENCES | PROBABILITY OF OBTAINING NO. OF POSITIVE DIFFERENCES *per cent* |
|---|---|---|---|---|
| Nickel | 43 (32.6) | 46 | 43 | 36 |
| Arsenic | 49 (37.1) | 44 | 39 | 30 |
| Cobalt | 56 (42.4) | 42 | 34 | 22 |
| Copper | 31 (28.5) | 55 | 46 | 19 |
| Manganese | 14 (10.6) | 64 | 54 | 17 |
| Iron | 31 (23.5) | 64 | 37 | <1 |
| Zinc | 23 (17.4) | 68 | 41 | <1 |

These results suggest that for the majority of metals no major systematic biases are present and application of techniques such as analysis of variance and Howarth and Thompson precision procedure should provide meaningful results. Results obtained for metals zinc, and iron, however, should be scrutinized carefully in light of their strong systematic bias. A high incidence of identical metal concentrations for individuals of a duplicate pair is also characteristic for all metals studied and intuitively appears unrealistically high considering: (1) that it occurs across the concentration ranges of each particular metal; and (2) the quoted sensitivity of the analytical method.

Results of the analysis of variance are presented in Table 3. As expected, the between-sample site variability is decidely higher than the within-sample site dispersion for all of the metals studied. This feature is both encouraging and desirable because the purpose of these regional surveys is to define a regional trend related to geological and geochemical phenomena; the greater the variability in metal concentrations between-sample sites the greater the ease of defining such trends.

TABLE 3
ANALYSIS OF VARIANCE OF RESULTS FOR
132 DUPLICATE PAIRS OF STREAM SEDIMENTS

| METAL | GRAND MEAN (GEOMETRIC)[1] | BETWEEN SITES $F_1$ | WITHIN SITES $F_2$ | VARIANCE COMPONENTS BETWEEN SITES % | VARIANCE COMPONENTS WITHIN SITES % |
|---|---|---|---|---|---|
| Zinc | 50 | 156.98[2] | 8.22[2] | 89 | 11 |
| Copper | 26 | 115.45[2] | 1.61 ns | 97 | 3 |
| Nickel | 15 | 59.51[2] | 2.81 ns | 91 | 9 |
| Cobalt | 8 | 40.70[2] | 0.20 ns | 99 | 1 |
| Manganese | 292 | 276.88[2] | 0.26 ns | 99 | 1 |
| Iron | 1.68 | 313.30[2] | 13.56[2] | 91 | 9 |

The test depends on the following null hypothesis:

(a) Between sample sites – mean metal contents are equal at each site. Degrees of freedom are $(m-1, m-1)$, where $m$ = number of sites = 132.

(b) Within sample sites – mean of samples $x1$, is equal to mean of duplicates $x2$. Degrees of freedom are $(1, m-1)$.

[1] All values are in ppm except for iron which is in per cent.

Probability ranges for accepting the null hypothesis:

[2] = $0.01 > P$; [3] = $0.05 > P > 0.01$; ns = $P > 0.05$

From the $F_2$ ratios given in column 3 in Table 3, it is seen that for zinc and iron distributions there are also significant differences between the groups of the first field-site duplicate and the second field-site duplicate, probably reflecting the systematic bias discussed earlier. It is important to note that where there is a significant difference between the two groups, and the within-site variance component is large, the data may be of little value in prospecting, irrespective of the significance of the test for geochemical variation.

According to Bolviken and Sinding-Larsen (1970) where there is a significant difference between duplicate pairs of samples at individual sample sites and the within-site variance component is relatively small no large deviation can exist for many duplicates. Two possibilities exist: (1) there is a minor deviation between duplicates at many sample sites and considered not to seriously hamper prospecting potential; and (2) there is a major deviation between duplicates at a few sample sites and considered to be serious if is not detected by inspection of the data. In our case the significant F ratio and relatively low within-site variance component for metals zinc and iron is accounted for by the former possibility and, as a consequence, these metals can be used to define real geological and geochemical trends.

Comparable investigations by Bolviken and Sinding-Larsen (1970) and Chork (1972) using similar-type data and tests found that the variation within sites was about 10 to 25 per cent and the variation between sites was about 75 to 90 per cent. These results are considered typical for low-density stream-sediment surveys.

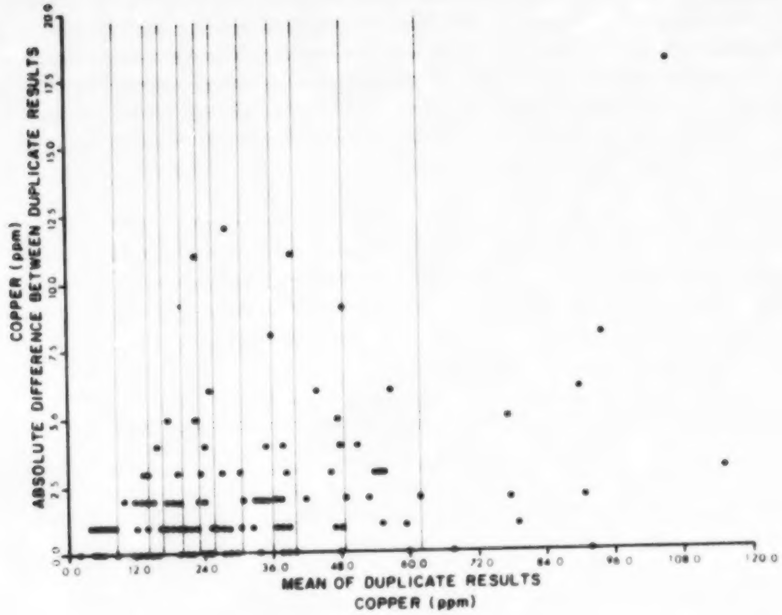

Figure 110. Absolute differences of paired data versus corresponding mean values of pairs, copper in stream sediments, British Columbia Regional Geochemical Survey.

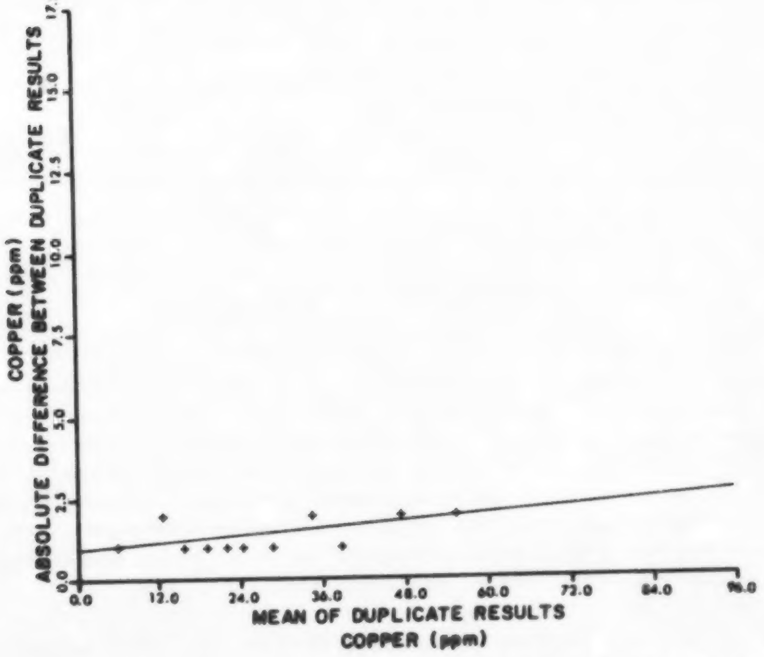

Figure 111. Linear model of average error as a function of concentration, copper in stream sediments, British Columbia Regional Geochemical Survey.

This is contrasted by results obtained from this study (Table 3) which exhibit surprisingly lower within-sample site variance, averaging less than 5 per cent of the total variability. The significance of these anomalous results is elaborated upon in a later section.

Results obtained from the Thompson and Howarth method are presented in Table 4 and illustrated graphically for copper on Figures 110 and 111. Although the regression of the median of absolute differences on the concentration means was only based on 12 points, analysis of variance proved significant at the 99 per cent confidence interval for all metals except cobalt (Table 4, column 6). A regression plot of copper illustrated on Figure 111, shows conclusively that simple linear regression more than adequately accounts for the relationship between the median of absolute differences and mean concentrations; thus it provides an excellent indictor of precision over the range.

TABLE 4
RELATIVE PRECISION ESTIMATES, THOMPSON–HOWARTH METHOD
BRITISH COLUMBIA REGIONAL GEOCHEMICAL DATA
(92H, 92I, and 92J)

| METAL | DETECTION LIMIT[1] | MAXIMUM VALUE | SLOPE | INTERCEPT | REGRESSION F–VALUE | PRECISION ESTIMATES AT SELECTED PERCENTILES 90th % | 95th % | 99th % |
|---|---|---|---|---|---|---|---|---|
| Zinc | 2 | 210 | 0.027[2] | 0.892 ns | 7.19[4] | 7.0 | 6.8 | 6.5 |
| Copper | 2 | 720 | 0.018[2] | 0.945[2] | 16.60[2] | 6.7 | 5.9 | 5.1 |
| Nickel | 2 | 1300 | 0.012[2] | 0.629[2] | 55.44[2] | 4.0 | 3.2 | 2.5 |
| Cobalt | 2 | 96 | 0.029[4] | 0.212 ns | 3.14[4] | 8.0 | 7.4 | 6.7 |
| Manganese | 5 | 3700 | 0.036[2] | 2.785 ns | 40.72[2] | 7.8 | 7.7 | 7.6 |
| Iron | 0.02 | 5.70 | 0.011[2] | 0.051[4] | 2.57[4] | 5.0 | 4.7 | 4.1 |

[1] All values are in ppm except iron which is in per cent.
Probability ranges for accepting t-tests on the slope and intercept and F-test on the regression:
[2] = 0.01 > P; [3] = 0.05 > P > 0.01; [4] = 0.10 > P > 0.05; ns = P > 0.10

Estimates of the slope also proved significantly different from zero at the 99 per cent confidence level (Table 4, column 4) for all metals except cobalt. However, only copper and nickel intercepts were found to be significantly different than zero (Table 4, column 5). This implies first, that the slope is major influence on the precision estimate of a given metal and second, that the magnitude of the slope reflects the relative precision. Examination of Table 4, column 4 reveals that nickel possesses the relatively lowest slope (0.012) whereas magnanese is the highest (0.036). The intercept for most of the metals is not significantly different from zero and the magnitude of the slopes is extremely small, therefore, the precision is incredibly low.

For example, Figures 110 and 111 illustrate for the metal copper: (1) the plot of absolute differences against means of duplicate pairs with the concentration range divided into equal frequency intervals; and (2) a plot of the regression of the median absolute difference against mean concentration of copper. To determine the precision as an absolute value obtain graphically the median absolute difference corresponding to a selected concentration value on the regression line and multiply by 2. Thus, for copper at the:

50th percentile (26 ppm) absolute precision = 2.8 ppm
95th percentile (59 ppm) absolute precision = 3.9 ppm
99th percentile (80 ppm) absolute precision = 4.7 ppm

## DISCUSSION OF RESULTS

In general, all data collected in stream sediment surveys contain errors that are acquired through sampling, laboratory analysis, and data handling. Taking the existence of sampling errors into account, a precision of

10 to 15 per cent at the 95 per cent confidence level is generally regarded as acceptable for laboratory variability in most exploration programs (Fletcher, 1981). Studies tailored to the evaluation of error in drainage surveys, such as Plant (1971), Howarth and Larsen (1971), Bolviken and Sinding-Larsen (1973), Plant, *et al.* (1975), and Chork (1977) generally concluded:

(1) Variable bias and variable precision introduced by secondary environment effects obscure the primary regional geochemical variation. The factors involved are complex and related to several variables in the primary and secondary environments investigated.

(2) Metal dispersion within-sample sites depends on such factors as:
  (a) concentration of the metal under investigation;
  (b) concentration of other metals (for example, iron);
  (c) homogeneity of sediment composition;
  (d) catchment size at sample site.

(3) The combined variability due to local variation and sampling error ranged from 10 to 25 per cent.

(4) Sampling errors tended to exceed analytical errors when precise analytical techniques such as atomic absorption spectrometry are used.

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Printed in Canada
Queen's Printer for British Columbia
Victoria, 1984 C

M50-367